3. LYSIMETERS

3.1 Introduction

Eighteen drive-point soil water solution samplers, referred to as lysimeters, were designed by the INEEL, constructed by Northeast Manufacturing of Meridian, Idaho, and installed using the INEEL sonic drill. The lysimeter design and operation are described in *OU 7-13/14 Integrated Probing Project Type B Probes Lysimeter Probe Design* (Clark 2001a). Lysimeters can be used to collect soil moisture solution samples (pore water) from either saturated or unsaturated sediments. The lysimeters have a semipermeable stainless steel membrane that allows water to move through but restricts air movement. Soil water is withdrawn from the surrounding soil by applying a lower pressure in the lysimeter than in the soil for a period of time to collect water in a chamber. Once water has accumulated in the lysimeter, a positive pressure is applied to push the water to land surface where it is placed in sampling bottles and submitted to laboratories for analyses. The pressure response in the lysimeter during sampling was recorded by connecting an incline pressure sensor. This information is used to evaluate the in situ water potential and how quickly water is collected by the lysimeter and to evaluate potential problems with the instruments. Pressure responses are presented for all of the lysimeters to evaluate their condition. Instruments were installed at two target depths: in the waste and in the underburden beneath the waste. The data evaluation information presented in this report is based on evaluation of field data from the instruments.

Eighteen direct push suction lysimeters were constructed and installed at the SDA of the RWMC in fall of 2001. The locations of the lysimeters are shown in Figure A-4 (Appendix A), and their depths are presented in Table 8. Eighteen direct push lysimeters were installed and instrumented as part of the WAG 7 OU 7-13/14 hydrologic characterization activities (Salomon 2001). Table 9 is a summary of the lysimeter samples obtained for FY 2002 including dates vacuum applied, date sampled, and volumes of moisture obtained. In April 2002, an initial evaluation of the sampling results indicated that the samplers were not consistently collecting sufficient moisture volumes for analysis or no water at all. Data loggers and transducers were obtained and connected to lysimeters to record their pressure response during sampling to indicate reasons for low sample volumes. Data from the pressure responses from the lysimeters during sampling along with an explanation follow in the results section. Several reports were produced detailing potential problems and solutions for the lysimeter and are included as Appendixes C, D, and E. Evaluation of field data and field testing suggests several field activities are required to determine the reason for the low-sampling volume and to make the remaining instruments operational (Appendixes C and D).

Table 8. Depths of direct push lysimeters installed at the Subsurface Disposal Area.

	Lysimeter Probe	Port Depth (ft)
1	DU-10-L1	9.8
2	DU-10-L2	7.0
3	DU-14-L1	16.0
4	DU-14-L2	7.9
5	DU-08-L1	16.1
6	DU-08-L2	14.1
7	743-03-L1	12.8
8	743-03-L2	9.8
9	743-08-L1	23.3
10	743-08-L2	9.0

Table **8**. (continued).

	Lysimeter Probe	Port Depth (ft)
11	743-18-L1	12.1
12	743-18-L2	12.8
13	SVR-12-1-L1	11.1
14	SVR-12-1-L2	5.8
15	Pit5-TW1-L1	12.2
16	Pit5-4-L1	10.6
17	741-08-L1	15.2
18	741-08-L2	7.8

Table 9. Summary of sampling results from direct push lysimeters.

Type B Lysimeter	7–9/5/2001	10–11/7/2001	4/29/2002	8/21/2002	11/2002
DU-10-L1	N	N	N	N	N
DU-10-L2	N	N	N	N	N
DU-14-L1	N	N	N	N	N
DU-14-L2	N	Y (–2 mL)	N	N	N
DU-08-L1	N	N	N	N	N
DU-08-L2	N	Trace droplets	N	N	N
743-03-L1	N	N	N	N	N (<–1 mL)
743-03-L2	N	N	N	N	N
743-08-L1	N	N	N	N	N
743-08-L2	N	N	N	N	N
743-18-L1	Y (–20 mL)	**N**	N	N	N
743-18-L2	Y (–10 mL)	**N**	N	N (<–1 mL)	**N**
SVR-12-1-L1	N	Trace droplets	N	N	N
SVR-12-1-L2	Trace droplets	Trace droplets	N	N	N
Pit5-TW1-L1	N	Trace droplets	N	N	N
Pit5-4-L1	Y (–10 mL)	N	N	N	N
741-08-L1	Trace droplets	Y (–20 mL)	Y (–20 mL)	Y (–20 mL)	N (<–1 mL)
`741-08-L2	Y (–5 mL)	Trace droplets	N	N	N

Y = yes, sample obtained (sample size)
N = no sample obtained

3.2 Construction, Installation, and Operation

Drive-point suction lysimeters are instruments that yield water sample data from specified depths. Conventional lysimeters with ceramic porous cups and plastic bodies have been available commercially for over 20 years. Stainless steel versions have been available for about 5 years. These versions are installed by drilling a borehole, placing the instrument at depth, and backfilling the borehole with a silica flour material or native sediment to provide a hydraulic connection. The drive-point suction lysimeters described here were developed specifically for this investigation to allow for emplacement within waste without generating drill cuttings at land surface.

The drive-point lysimeter consists of a drive point with a sealed porous stainless steel membrane on the exterior that is connected to a sealed water reservoir with drive tubing extending to land surface and two smaller tubes inside the drive tube to withdraw water samples to land surface. Figure 6 shows a prototype lysimeter with clear sides for illustrative purposes. Inside the water reservoir, there is a water line and check valve that moves water from the porous stainless steel membrane into the water chamber. The height of the line and the check valve is intended to prevent water or airflow back into the porous membrane area while withdrawing the water sample. The water reservoir has two tubes with one that terminates near the top of the chamber and with the other extending to near the bottom of the reservoir. These metal tubes are connected to plastic tubing, which extends to land surface. The design and operation of the instruments are presented in *OU 7-13/14 Integrated Probing Project Type B Probes Lysimeter Probe Design* (Clark 2001a), and sampling procedures are described in a procedure (see Footnote D).

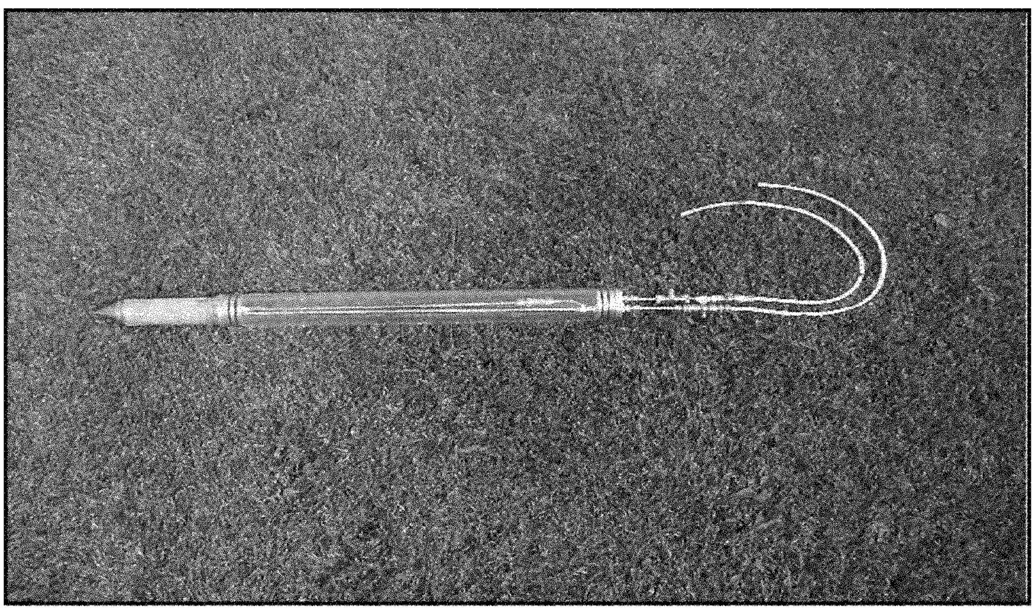

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Figure 6. Prototype lysimeter.

During installation, the porous stainless steel membrane is wetted up (saturated) with water before installation and then the instrument driven to depth using a combination of hydraulic down pressure and sonic vibration. The porous stainless steel is supposed to remain saturated once in the ground to prevent air from moving (leaking) through the porous stainless steel. The lysimeters are permanently installed so they cannot be serviced or maintained, except by way of the tubing that is accessed at land surface.

Instruments were installed at multiple depths primarily near the top of the waste and near the base of the waste next to underlying sediments. Instruments were delivered to the SDA with the porous stainless steel membrane unattached; the porous stainless steel was wetted before insertion, assembled at the drill site, and installed using the sonic driving technique. Probes were installed by driving using the drill rig down pressure until consolidated sediments were encountered (often at about 2 ft). Then, the sonic drive head activated, and the probe sonically pushed to specified depth.

The suction lysimeter is sampled by applying a partial vacuum (less than atmospheric pressure) and sealing the instrument for a time period of days. If the porous stainless steel is saturated with water and the remainder of the instrument is sealed, the water chamber will retain a vacuum for an extended time period. The pores in the stainless steel are sized so that, once the pores are filled with water, air cannot displace the water until positive or negative pressures exceed f700 cm (equivalent water pressure). All pressures are referenced to atmospheric pressure, so if the pressure is positive, it is greater than atmospheric, and, if the pressure is negative, it is less than atmospheric or a partial vacuum. If the porous stainless steel is dewatered or if there is an air leak at a fitting or a damaged seal, it will allow air to enter into the lysimeter, and water cannot be obtained.

The partial vacuum applied on the sealed lysimeter exerts a differential pressure across the porous membrane, and water in the surrounding sediment is pulled toward the device through the membrane and then collects in the lower chamber. The lower chamber inside the porous membrane is initially filled with water. As water is drawn through the membrane, it water moves up the tubing and through the check valve where it drips into the upper water chamber. This upper chamber can retain over 500 mL of water. Water is removed from the upper chamber by pressurizing the tube that terminates at the top of the water chamber, forcing water up the other tube to land surface. The check valve prevents this extraction gas from entering the porous membrane and dewatering the membrane.

Following installation, the lysimeters cannot be removed for laboratory testing but can be field tested to verify their proper operation. The lysimeters were placed under moderate to very high stresses during installation from the sonic insertion technique. The probe insertion technique used a combination of the direct push technique, using the drill rig down pressure to advance the probe, and the sonic technique where the drill string and probe are vibrated to assist rapid penetration. The vibration from the sonic drilling has the potential to loosen fittings or dewater the porous stainless steel

3.3 Pressure Response in Lysimeters During Sampling

The pressure response in a lysimeter follows a predictable pattern when operating correctly. A partial vacuum is applied throughout the device, and the tubes are sealed. This vacuum starts to pull water from the surrounding sediment quickly, but then as less water is available and the hydraulic conductivity is decreased because of local dewatering of the sediment, the flow into the instrument decreases in a curve that can be approximated by a logarithmic curve in the form of

$$y=C\ln(x)-D \qquad (1)$$

where

C = constant

D = constant.

The pressure decreases slowly until the pressure approximates the ambient soil water potential in the surrounding sediment. Deviation from this response, like holding a constant pressure or a rapid decrease in pressure, suggests that the sediment is too dry to sample or that there are air leaks in the instrument, respectively.

As the water content in the surrounding sediment decreases, the water potential and the hydraulic conductivity also decrease. The relationship between the water potential and water content is described by the soil water characteristic curve derived from core samples in the laboratory. The characteristic curve along with saturated hydraulic conductivity is used to calculate the unsaturated hydraulic conductivity versus water potential or water content using relationships described by van Genuchten (1980) and Mualem (1976). The decrease in hydraulic conductivity with lower water potential or water content is nonlinear and controls the water entry into the lysimeter. These relationships are specific to the individual sediments and are primarily dependant on the texture and sorting of the material.

High differential pressures across the porous membrane may rapidly dewater sediments around the membrane and lower the hydraulic conductivity so that water movement in the lysimeter is slowed. Thus, it is recommended that the pressure differential between the vacuum applied in the lysimeter and the soil water potential in the surrounding sediment be kept to a minimum (often in the –100- to –150-cm range). Sediment in the range of 0- to –200-cm water potential has the highest probability of yielding water in a reasonable period of time (hours to days). Fine-grained sediments with lower water potentials may yield water extremely slowly (weeks). The hydraulic conductivity in courser sediments (sand) decreases more rapidly than fine-grained sediments so that sampling rates are very low in these sediments below about -100 cm. The ambient soil water potential in the sediments at the time of sampling, which varies over time, ultimately controls the availability of water for sampling. Sediments near land surface away from sources of recharge will generally have lower water potential while deeper sediments near sources of water will have higher water potentials (Laney et al. 1988).

Pressure responses and water collection for sediments representative of the SDA are summarized in Table 10. For sediments in the water potential range of 0 to –700 cm, the final pressure in the lysimeter should approach the water potential of the surrounding sediments. An exception would be if there was a leak in the apparatus or the porous membrane that was not h1ly saturated. Leaks in the apparatus from poor connections, torn seals, or damaged stainless steel should have the pressure in the lysimeter approach the atmospheric pressure (reporting 0 cm pressure) or the ambient pressure at depth. Lysimeter pressure instruments with partially wetted porous stainless steel should approach the air entry pressure of the steel, which can range from –700, if nearly saturated, to 0, if less than h1ly saturated. This relationship of saturation versus water potential has not been determined for the porous stainless steel; however, the effective porosity of the steel is only about 6% so small changes in saturation my significantly decrease the air entry pressure.

Soil water potential and water level data collected from sediments between pits and trenches suggest that saturated conditions only form for short times of the year (days to a couple of weeks) (Hubbell 1993). These periods of saturation occur in the late winter and spring in conjunction with snowmelt and infiltration and generally occur near areas with ponded water at land surface. Following infiltration events and saturation, the water potentials decline slowly over the year until the next infiltration event that recharges the sediment. Shallower depths have the fastest and greatest changes in water potential while deeper sediments have smaller water-potential fluctuation. The annual water-potential response within and below buried waste has not been measured previously at this site.

Table 10. Summary of pressure responses based on water potential.

Soil Water Potential	Lysimeter Response
Saturated	Water available for sampling
0 to about –200 cm	Water available for sampling
-200 to about –350 cm	Small quantities available for sampling at a slow rate
Below about –350 cm	Hydraulic conductivity too low to collect water; holds pressure
Below –700 cm	No water available; lysimeter doesn't hold vacuum

3.4 Lysimeter Pressure Testing Equipment

During lysimeter sampling activities, many of the lysimeters did not yield sufficient volumes of water, so data loggers were used to collect the pressure data to assist in determining the most logical potential problems. The pressure sensors used to collect data from the lysimeters are Model 15 Electronic Engineering Innovations data loggers (Las Cruces, New Mexico) that measure over -800 to +800 cm water pressure. The programmable data logger and pressure sensor are contained in a waterproof container with a brass tube connector that connects to the airline of the lysimeter (see Figure 7). The pressure sensors and data loggers are calibrated by Electronic Engineering Innovations before delivery to the INEEL.

The pressure response from the data loggers and pressure sensors is believed to be influenced by the combination of temperature variations on the logger and tubing above land surface. Increasing the temperature in the tubing causes the pressure to increase and may affect the output of the pressure sensor. The effect on the electronics of the data logging system has not been investigated but is suspected to influence the readings. Field pressure testing was conducted on the 18 lysimeters to record their responses during field sampling activities.

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Figure 7. Data logger and pressure sensor configuration.

The pressure response of the lysimeters can be interpreted to determine the time for sampling, ambient water potential, and potential reasons for limited moisture samples. Pressure responses will be presented with evaluation of the data. Additional pressure curves from other sampling dates are included in Appendix C. Recommendations for field activities to evaluate the operation of the lysimeters are presented in Appendix D.

3.5 Lysimeter Pressure Response Results and Discussion

Eighteen direct push solution samplers (suction lysimeters) installed at the SDA had a vacuum applied in the April–May 2002 timeframe (see Figures 8–25). They then had a vacuum applied in the July-August time period with four yielding 5–20 mL and two providing just a trace of water. Vacuum pressure tests have been run on all of the sonic emplaced lysimeters. In general, the pressure data indicate that the majority of instruments are not holding the vacuum pressure for sufficient time to obtain a water sample. The soil water potential of the soil is probably in the range of –100 to –300 cm, but several lysimeters have air leaks so they will only hold a vacuum of –50–0 cm, which is higher pressure than the soil. The lysimeter must be under lower pressure to pull the water from the surrounding sediment. This pressure response, with the pressure rising quickly to near atmospheric pressure (0 cm) along with the small sample sizes, indicates the probes are not hnctioning properly.

DU-10-L1—read from –300 to –150 in *3* days and then dropped rapidly to zero pressure in a few hours. This indicates that water was initially being collected but that the vacuum was lost before the water was able to fill to the water-sampling line (– 30 mL). The rapid decline in the pressure (5 hours) at this time suggests a leak in the system allowing air into the lysimeter. No water has been collected by this lysimeter to date. This indicates a leak in a fitting, seal, or the porous stainless steel.

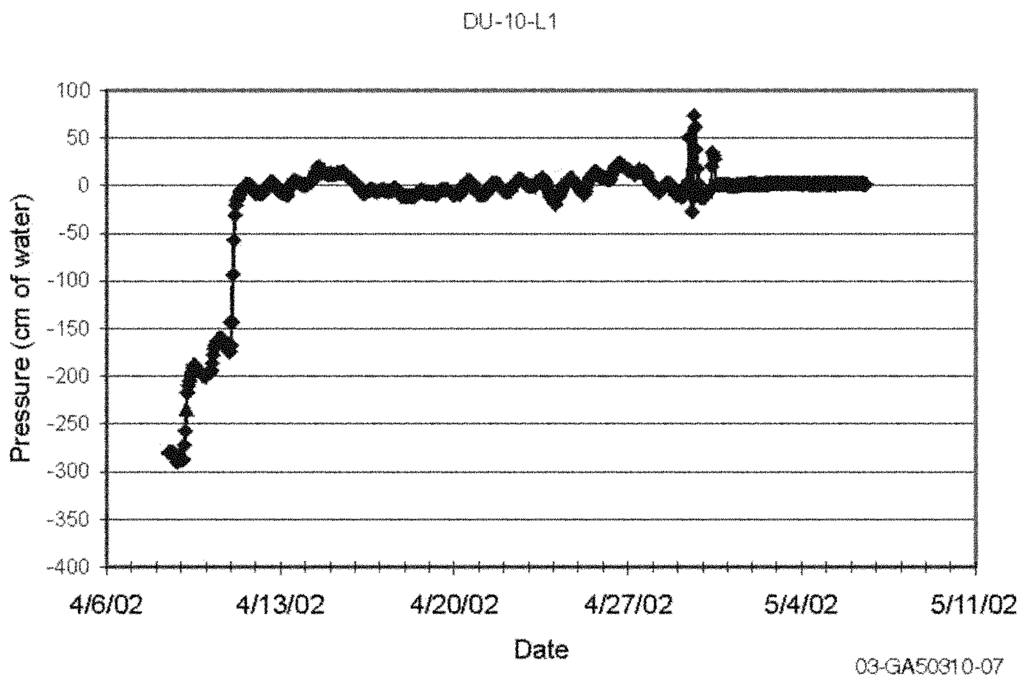

Figure 8. DU-10-L1.

DU-10-L2—pressure dropped to 50 cm in less than 10 minutes and then held pressure for greater than 2 weeks. It is believed that there is a leak in the lysimeter so that it will not hold a vacuum greater than -50 cm. The soil water potential is less than the –50-cm air entry pressure, so there is not a sufficient pressure differential to pull the water into the lysimeter; thus, no water is collected. This pressure response suggests the bubbling pressure in this instrument is about 50 cm. No water has been collected by this lysimeter. This pressure response indicates there is a leak in a fitting, seal, or the porous stainless steel.

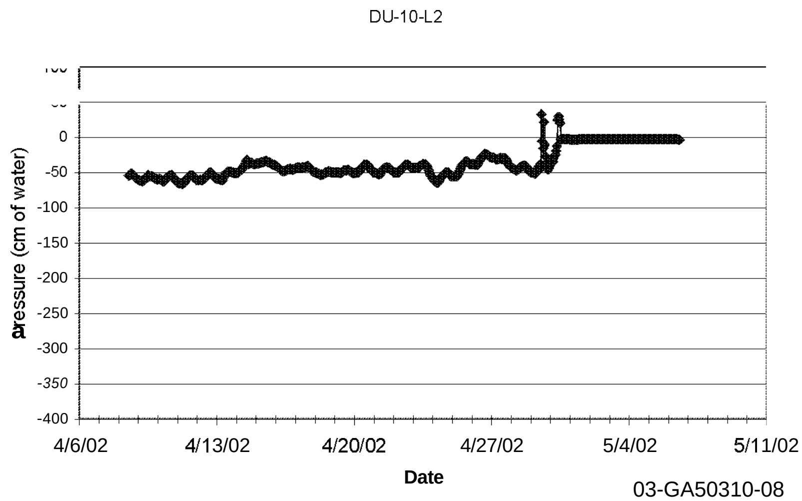

Figure 9. DU-10-L2.

DU-14-L1 — pressure dropped to -100 cm in less than 40 minutes, and the reading varied from –100 to 0 cm. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure drop does not allow enough time to collect a water sample. The pressure oscillations following the pressure drop may be related to temperature fluctuations. No water has been collected by this lysimeter.

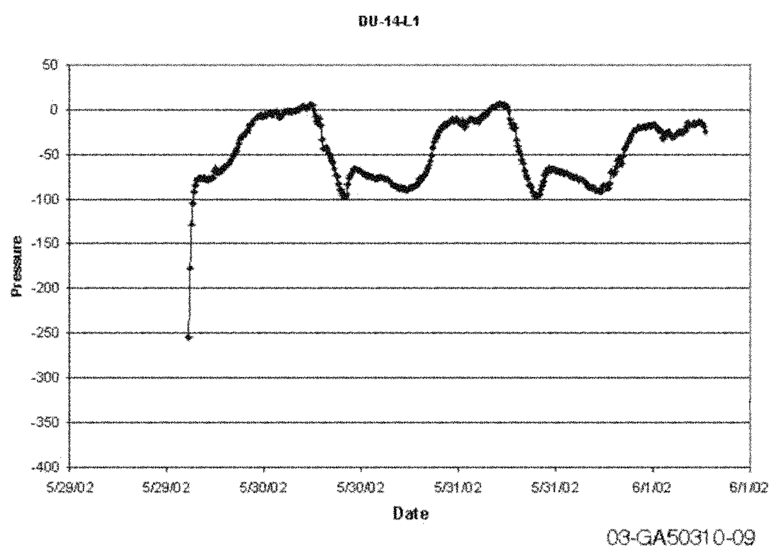

Figure 10. DU-14-L1

DU-14-L2—pressure dropped to -100 cm in less than 90 minutes, and the reading varied from about -100 to +30 cm. This indicates a leak in a fitting, seal, or the porous stainless steel. The rapid pressure drop does not allow enough time to collect a water sample. The pressure oscillations following the pressure drop appear to be related to temperature fluctuations in the logger, sensor, or tubing. Only 2 mL of water have been collected by this lysimeter on one sampling.

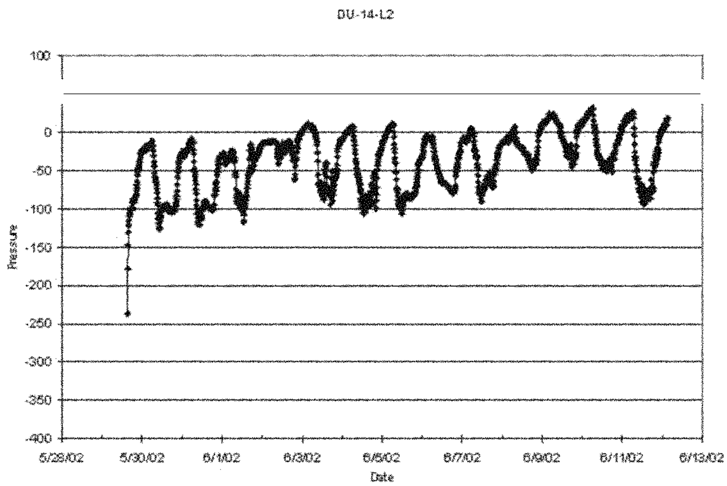

Figure 11. DU-14-L2.

DU-08-L1—pressure dropped to -50 cm in less than 30 minutes, and the reading varied then from about -30 to +25 cm. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure drop does not allow enough time with a pressure differential to collect a water sample. The pressure oscillations following the pressure drop appear to be related to temperature fluctuations in the logger, sensor, or tubing. No water has been collected by this lysimeter.

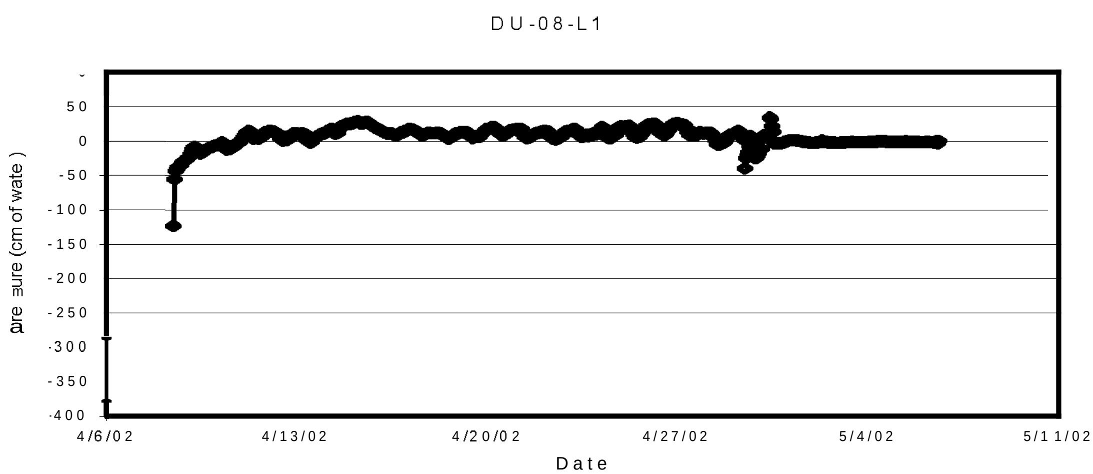

Figure 12. DU-08-L1

DU-08-L2—the pressure response shows the anticipated response for hnctional lysimeters. The pressure dropped from -300 cm to -50 cm in about a day and then shows minor oscillations, presumably caused by temperature fluctuations at land surface. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure drop may not have allowed enough time to collect a water sample. Only a trace of water has been collected during one sampling episode.

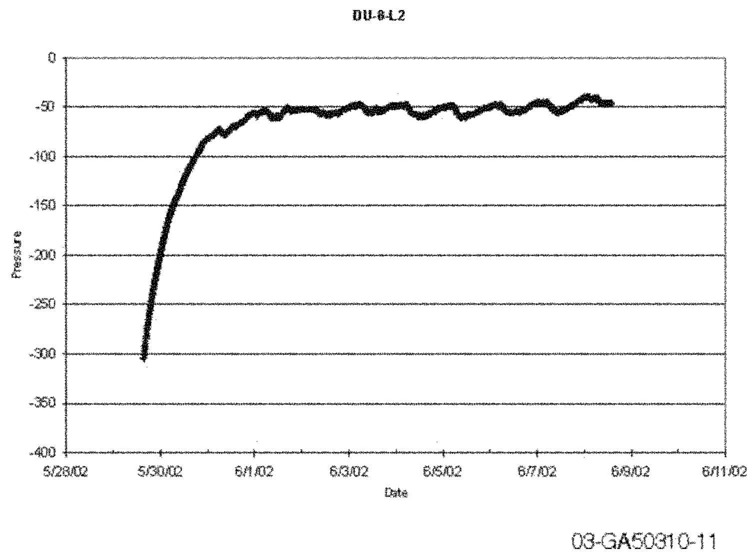

Figure 13. DU-08-L2.

743-03-L1—pressure dropped to below –200 cm in less than 1 hour. This indicates a leak in a fitting, seal, or the porous stainless steel. The pressure oscillated around 0 cm. Only a trace of water has been collected by this lysimeter on one occasion (not this sampling).

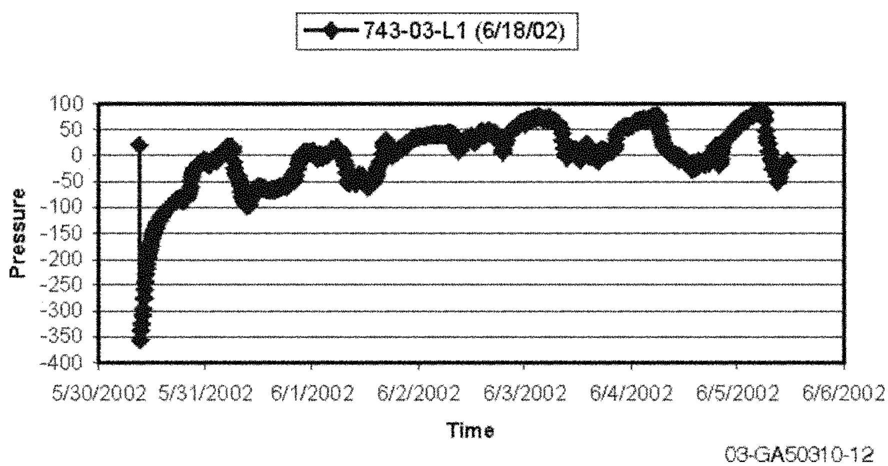

Figure 14. 743-03-L1.

743-03-L2—pressure dropped to 0 cm in less than 10 minutes, suggesting a leak. This indicates a leak in a fitting, seal, or the porous stainless steel. No water has been collected by this lysimeter.

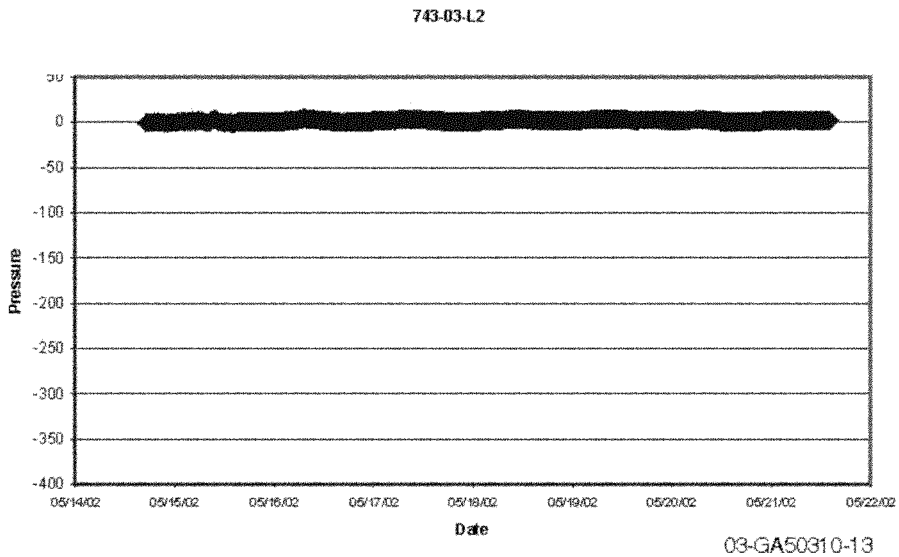

Figure 15. 743-03-L2.

743-08-L1—pressure dropped to -0 cm in less than 10 minutes. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure drop does not allow enough time with a pressure differential to collect a water sample. No water has been collected by this lysimeter.

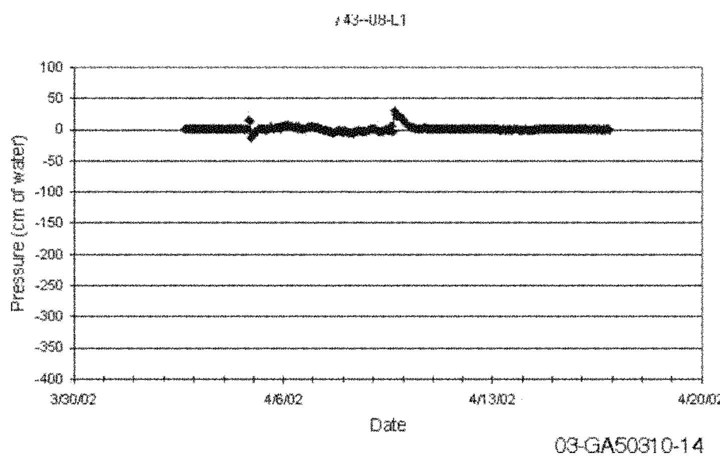

Figure 16. 743-08-L1.

743-08-L2—pressure dropped to -0 cm in less than 10 minutes. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure drop does not allow enough time with a pressure differential to collect a water sample. No water has been collected by this lysimeter.

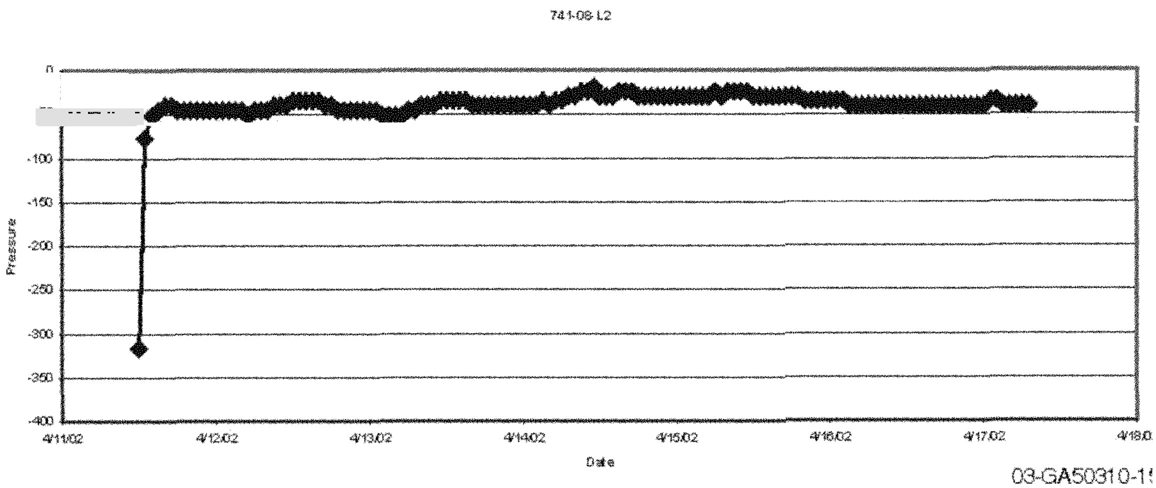

Figure 17. 743-08-L2.

743-18-L1—read from –300 to –200 over the sampling period. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure suggests that the lysimeter can hold a vacuum, and 20 mL were obtained in the following sampling. No water has been collected since that time.

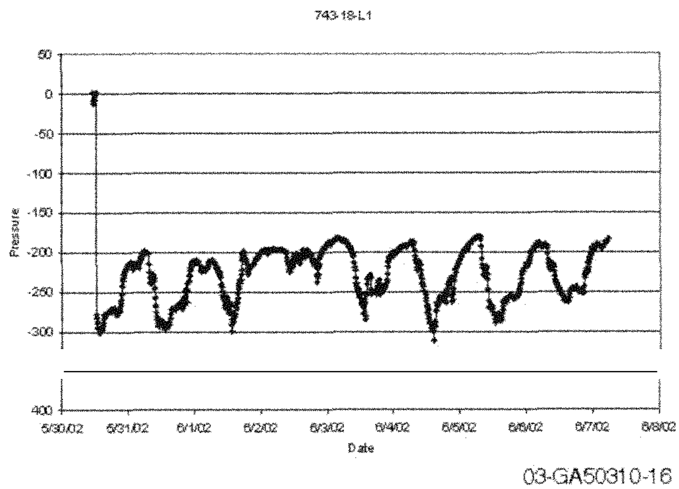

Figure 18. 743-18-L1.

743-18-L2—read from –300 to –100 in a few hours and then continued to drop to oscillate around zero pressure. This indicates a leak in a fitting, seal, or the porous stainless steel. This pressure response suggests that water was initially being collected. About 10 mL were collected on the following sampling event. The relatively rapid vacuum decline indicates a leak in the system allowing air into the lysimeter. Water was collected by this lysimeter on one other occasion. Larger samples of water could be collected if the vacuum could be maintained for a longer time period.

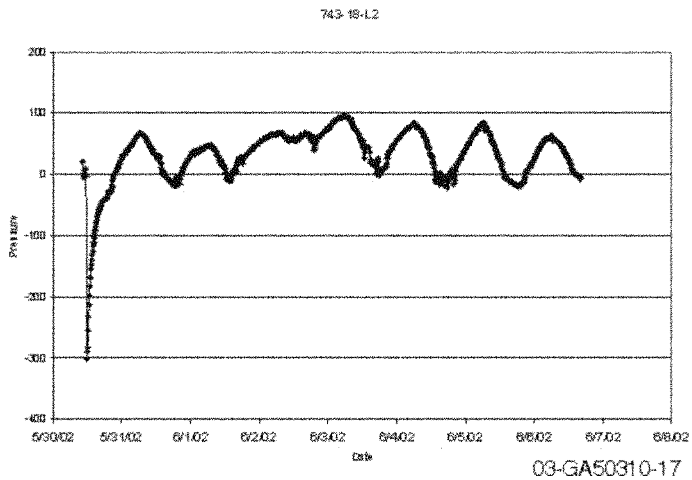

Figure 19. 743-18-L2.

SVR-12-1-L1—this lysimeter pressure dropped to oscillate about –50 cm within a few hours. This indicates a leak in a fitting, seal, or the porous stainless steel. It has only collected a trace of water on a subsequent sampling episode.

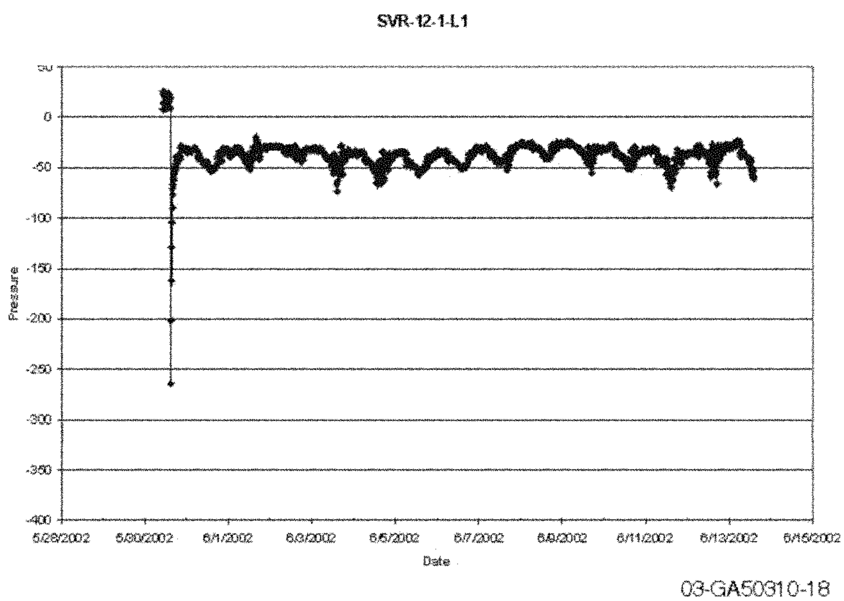

Figure 20. SVR-12-1-L1.

SVR-12-1-L2—pressure started at –325 and dropped to –50 in about 3 hours. This indicates a leak in a fitting, seal, or the porous stainless steel. This lysimeter has collected only a trace of water on several sampling episodes.

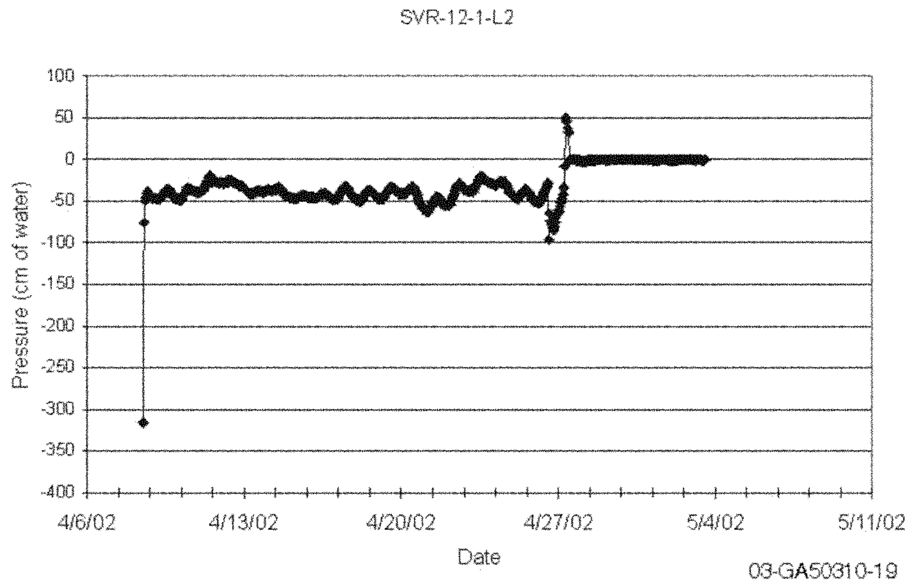

Figure 21. SVR-12-1-L2

Pit5-TW1-L1—the pressure dropped to about –50 cm in less than 10 minutes. This indicates a leak in a fitting, seal, or the porous stainless steel. This lysimeter has only collected a trace of water once during sampling.

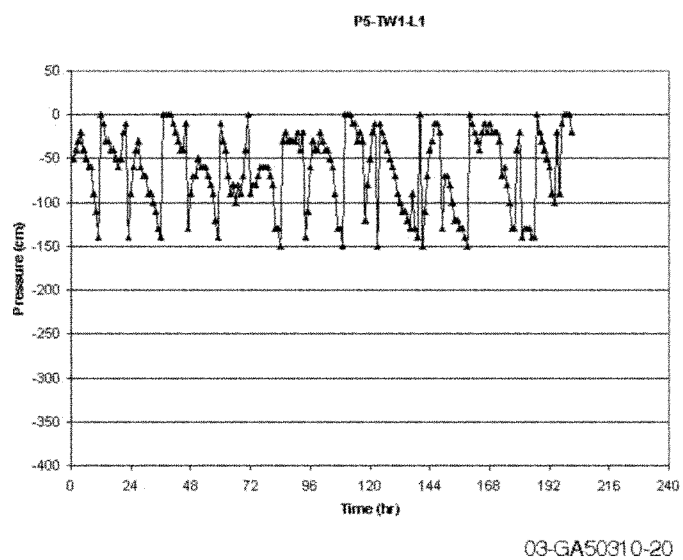

Figure 22. Pit5-TW1-L1.

Pit5-4-L1—read about -10 cm in less than 10 minutes. This indicates a leak in a fitting, seal, or the porous stainless steel. However, about 10 mL were collected in one of the subsequent sampling episodes, but no samples have been collected since that time.

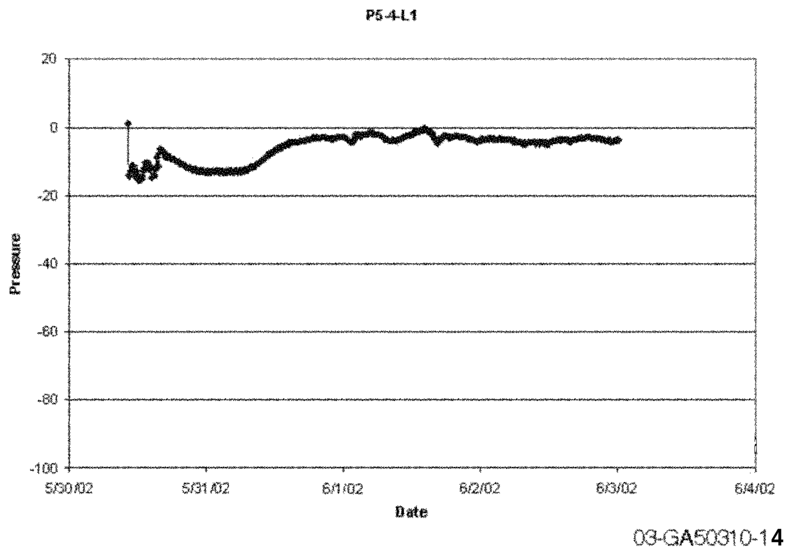

Figure 23. Pit5-4-L1.

741-08-L1—this lysimeter has consistently collected about 10 mL of water in each sampling episode, except the last one. The pressure drops rapidly, but the sediment must be very wet to allow sample collection over the short period that the vacuum is being held. This indicates a leak in a fitting, seal, or the porous stainless steel.

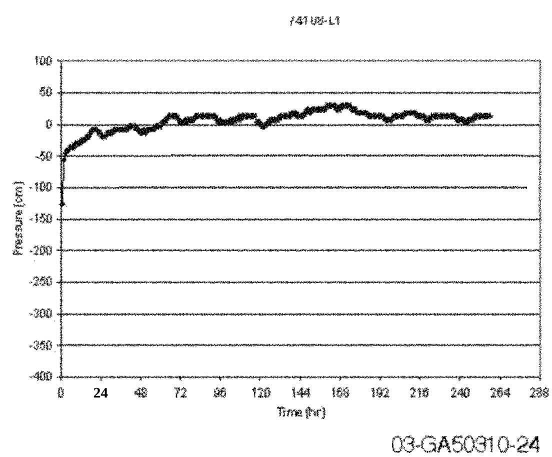

Figure 24. 741-08-L1.

741-08-L2—read about –10 cm in less than 10 minutes. This indicates a leak in a fitting, seal, or the porous stainless steel. However, about 5 mL were collected from the subsequent sampling episode but only a trace of water in the following episode and none since those times.

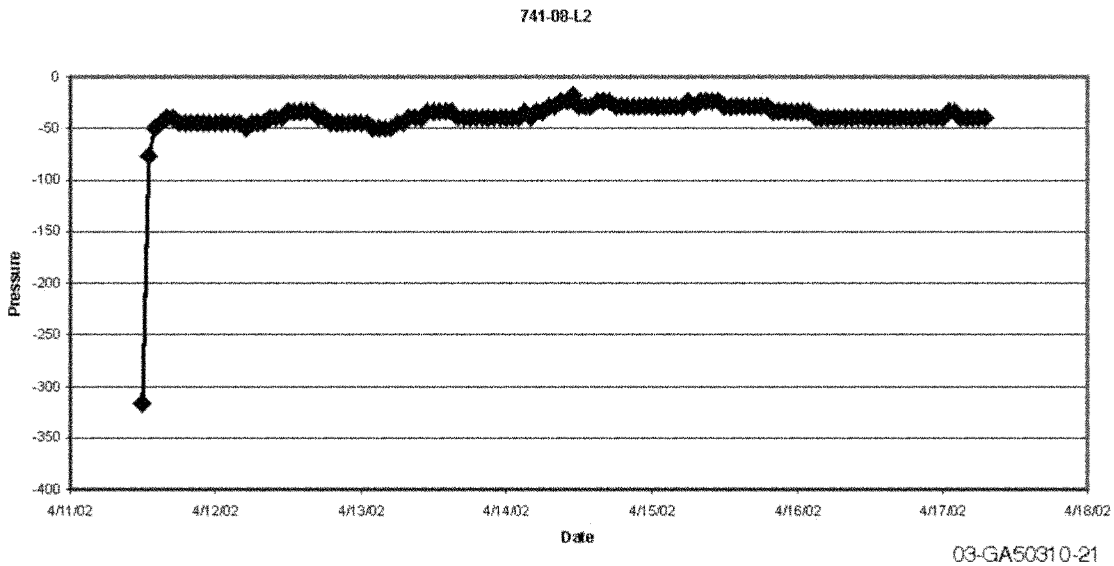

Figure 25. 741-08-L2.

The rapid drop in differential pressure (partial vacuum) in most of the lysimeters from –50 to 0 cm, as well as the small sample sizes, suggests there are air leaks in the instruments. It is unlikely that all of the lysimeters are located in sediments that have water potential less than –700 cm, in particular the deeper lysimeters. The following pressure responses from the lysimeters seem consistent:

- One response is a rapid drop to 0 cm in less than 1 hour and commonly less than 10 minutes with small oscillations around the 0 reading. Examples of this pattern are observed in DU-08-L2, 743-08-L1, 741-08-L1, and, to a lesser degree, DU-10-L1. It is suggested that since there is a fast drop in differential pressure and no oscillations suggesting that is holding pressure, the lysimeters have a loose fitting or a break in the device allowing rapid air entry so that the pressure is the same in the lysimeter tubing and the reference pressure (atmospheric pressure).

- The second response is a rapid pressure drop to about –50 cm and oscillations about that pressure. Examples of this response are seen in DU-10-2, DU-14-L1, DU-14-L2, SVR-12-1-L1, 741-08-L2, and P5-TW1-L1. It is suspected that these lysimeters had their porous stainless steel membranes partially dewatered by handling or the sonic vibration during installation.

- A third response is a steady reading such as seen in 743-18-L1, which had a pressure that oscillates about –250 cm.

Since many of the lysimeters pressure response indicates that the differential pressure was not maintained for extended time periods, a tank was connected to the lysimeter to increase the time the differential pressure is maintained. This technique has been successfully used for other (ceramic cup) lysimeters located between pits and trenches at the **SDA.** Appendix E presents a listing of the dates that tanks were used as well as the sizes of the tanks.

A rapid decrease in pressure while a tank is used suggests a large leak. An alternative way to extend the time the differential pressure is maintained is to use a vacuum pump. This technique should be acceptable for overcoming leaks from loose fittings, but if the leak is caused by dewatered porous stainless steel membranes, a vacuum pump should probably not be used because it may displace more pore water out of the membrane, further lowering the bubbling pressure. This possibility should be tested in the laboratory before using vacuum pumps on lysimeters where the porous stainless steel membranes may have been dewatered.

3.5.1 Potential Problems with the Lysimeters

There are three potential problems with the lysimeters. The first is a mechanical problem(s) that allows air to leak into the device. Air leaks into the lysimeter reduce the time there is a pressure differential across the membrane to collect water samples. A mechanical problem can occur from the stresses applied during installation such as the fittings being loosened; the plastic tubing stretched or twisted; or there may be leaks past the O-ring seals where the porous stainless steel contacts the body of the lysimeter.

The second problem is the porous membrane was not hlly wetted when the instrument was installed, or the sonic vibration during installation drove the water from the porous membrane. There is no way to rewet the stainless steel from the interior since there is a check valve that prevents water from getting from the upper chamber to the lower chamber where the membrane is located. Limited testing does indicate that the membrane may rewet over time when in contact with moist sediments. It is unknown how long this natural wetting would take.

The third possibility is that the sediment is too dry to sample (i.e., the soil water potential of the surrounding sediment is lower than the pressure applied within the lysimeter, so there is no hydraulic gradient to pull water into the lysimeter). Data from the tensiometers indicate that this is most likely at the shallowest instrument depths (less than **8-ft** depth). As more tensiometers are shown to be working correctly (performing calibration checks or wiring), it may become evident that the soil is too dry to sample. A detailed list of the potential failure modes for lysimeters and proposed solutions is attached in Appendix D.

3.6 Summary of Recommendations

Lysimeters should have additional field testing performed to determine why they are allowing air entry into the devices so rapidly. The tubing should initially be pressure checked to ensure that there are no leaks in the tubing, fittings, or the upper portion of the lysimeter. Once this has been completed, solutions can be implemented or other potential problems can be considered. Real-time feedback in the field is necessary to properly evaluate the instruments. This evaluation will determine which instruments are hlly hnctional and which require additional work or abandonment. The potential for dewatering of the porous stainless steel during installation should be evaluated, and alternate drilling techniques should be considered that reduce the installation stresses. The sonic emplacement technique may dewater the porous stainless steel during installation because of the high acceleration (up to 500 g). If the porous stainless membrane was dewatered, it may require several fillings or specialized refilling procedures to ensure full wetting of the porous stainless steel. A report by Sisson et al. (2002) presents data from less complex tensiometers that have been in operation for several years.

If the leaks are in the tubing or fitting and not in the porous stainless steel, a possible solution is to apply a vacuum for a longer time period by attaching a vacuum tank or vacuum pump. Vacuum tanks are simpler to use than pumps but will only work if there is a small leak. Recording the pressure drop over time will provide information as to the leakage rate that needs to be overcome. If the leakage rate is large, a vacuum pump may be required to apply a constant pressure for an extended time period.

The exact mechanism(s) causing air leakage into the lysimeter that is inhibiting water collection is unknown. Until the failure mechanism is determined, it is recommended that the instrument design be modified for new instruments to eliminate the most probable potential sources of failure. These design changes include a way to wet the porous membrane following installation and eliminate the O-ring seals by welding the porous membrane to the tip (preferably by Mott—the manufacturer of the porous stainless steel).

3.7 Analytical Data

The analytical data resulting from the samples obtained from the waste mne lysimeters are reported in the *FY* 2002 ***Environmental Monitoring Report for the Radioactive Waste Management Complex*** (Olson et al. 2003). The reported results are reproduced here and are presented by contaminant as they are in the referenced report.

3.7.1 Americium-241

Three waste zone soil moisture samples were collected and analyzed for Am-241 in FY 2002 with no positive detections. The samples were collected from Lysimeter 741-08-L1, which is located in the neptunium and americium focus area of Pit 10.

3.7.2 Neptunium-237

Two waste zone soil moisture samples were collected and analyzed for Np-237 in FY 2002 with two positive detections (see Table 11). Both samples were collected from Lysimeter 741-08-L1, which is located in the neptunium and americium focus area of Pit 10.

Table 11. Neptunium-237 detections in Subsurface Disposal Area waste zone soil moisture (lysimeter) samples.

Lysimeter	Depth (ft)	Sample Date	Sample Volume (mL)	Radionuclide	Sample Concentration ± 1σ (pCi/L)	MDA[a] (pCi/L)	RBC[b] (pCi/L)	Sample ID	L&V Report ID
741-08-L1	15.2	11/7/01	–15	Np-237	**22 ± 6P**	11	7.1	IPL006013A	DNT-060-02
741-08-L1	15.2	4/29/02	–20	Np-237	**6.1 ± 1.7**	3.1	7.1	IPL057013A	SOS-019-02

MDA = minimum detectable activity RBC = risk-based concentration ID = identifier L&V = limitation and validation

Note 1: Red bold font indicates a sample concentration exceeding the 1E-05 RBC.

Note 2: The concentration with a "P" subscript is a positive and validated detection that the pmject technical team deems questionable. The result is questionable because Np-237 was not detected m the laboratory-generated duplicate, and the laboratory control sample result had a low bias. Therefore, the result can only be used as an estimated quantity.

a. The MDA is commonly referred to as the detection limit and is unique to each individual sample analysis result.
b. The RBC does not apply to soil moisture samples, and is provided only as a basis of comparison.

3.7.3 Plutonium

Two waste zone soil moisture samples were collected and analyzed for PU-238, PU-239, and Pu-240 in FY 2002 with two positive detections of PU-239 and Pu-240 (see Table 12). The samples were collected from Lysimeter 741-08-L1, which is located in the neptunium and americium focus area of Pit 10. The PU-239 and Pu-240 results reported in Table 12 exceed the 1E-05 risk-based concentrations (RBC) for drinking water.

Table 12. Plutonium-239 and plutonium-240 detections in Subsurface Disposal Area waste zone soil moisture (lysimeter) samples.

Lysimeter	Depth (ft)	Sample Date	Sample Volume (mL)	Radionuclide	Sample Concentration ± 1σ (pCi/L)	MDA[a] (pCi/L)	RBC[b] (pCi/L)	Sample ID	L&V Report ID
741-08-L1	15.2	11/7/01	–15	Pu-239/240[c]	**35 ± 10**	11	3.5	IPL006013A	DNT-060-02
741-08-L1	15.2	4/29/02	–20	Pu-239/240[c]	**37 ± 12**	16	3.5	IPL057013A	SOS-019-02

MDA = minimum detstable activity RBC = risk-based concentration W = identifier L&V = limitation and validation

Note 1: Red bold font indicates a sample concentration exceeding the 1E-05 RBC.

a. The MDA is commonly referred to as the detection limit and is unique to each individual sample analysis result.
b. The RBC for drinking water does not apply to soil moisture samples and is provided only as a basis of comparison.

The detections and existence of **Pu-239** and **Pu-240** at the **741-08** lysimeter location are substantiated by the facts that **Pu-239** and **Pu-240** were detected in the laboratory-generated duplicate at a concentration similar to the original analysis result, the November **2001** and April **2002** results are nearly identical, and the gamma-logging data show significant levels of plutonium, americium, and neptunium.

3.7.4 Uranium

Two waste zone soil moisture samples were collected and analyzed for uranium in FY **2002** with significant concentrations detected in both samples (see Table **13).** The samples were collected from Lysimeter 741-08-L1, which is located in the neptunium and americium focus area of Pit 10. All of the uranium results reported in Table **13** exceed local soil moisture backgrounds and 1E-05 RBC for drinking water.

Table **13.** Isotopic uranium detections above local soil moisture background in Subsurface Disposal Area waste zone soil moisture (lysimeter) samples.

Lysimeter	Depth (ft)	Sample Date	Sample Volume (mL)	Radionuclide	Sample Concentration ± 1σ (pCi/L)	MDA[a] (pCi/L)	Soil Moisture Background[b] (pCi/L)	RBC[c] (pCi/L)	L&V Report ID
741-08-Ll	15.2	11/7/01	~15	U-233/234	**1800 ± 186**	25	3.0	6.7	DNT-60-02
				U-235	**42 ± 12$_J$**	19	0.5	6.6	DNT-60-02
				U-236	**91 ± 20$_J$**	18	Not established	7.1	DNT-60-02
				U-238	**291 ± 47**	14	1.5	5.5	DNT-60-02
741-08-L1	15.2	8/21/02	~20	U-233/234	**1770 ± 274$_J$**	16	3.0	6.7	SOS-019-02
				U-235/236	**156 ± 32$_J$**	14	0.5	6.6	SOS-019-02
				U-238	**348 ± 66$_J$**	11	1.5	5.5	SOS-019-02

MDA = minimum detectable activity RBC = risk-based concentration L&V = limitation and validation

Note 1: **Red bold font** indicates a sample concentration exceeding the 1E-05 risk-based concentration (RBC). **Black bold font** indicates a sample concentration less than the RBC and greater than local soil moisture background concentrations.

Note 2: Concentrations with a "J" subscript are positive detections with an assigned "J" data qualifier flag. The "J" qualifier flag was assigned to the November 2001 result because of limitations associated with discriminating and quantifying U-235 and U-236 using alpha spectrometry. The April 2002 data were flagged "J" because a contractually required duplicate analysis could not be performed to assess analytical precision as a result of insufficient sample volume. The reported concentrations of the "J" qualified results should only be used as estimated quantities.

a. The MDA is commonly referred to as the detection limit and is unique to each individual sample analysis result.
b. Local soil moisture background concentrations for uranium isotopes are averages of approximately 17 results obtained from 1998 to 2002 in the "O" wells and Well D15 outside of the Subsurface Disposal Area.
c. The RBC for drinking water does not apply to soil moisture samples and is provided only as a basis of comparison.

The uranium analyses were performed by alpha spectrometry, which generally cannot discriminate **U-235** and **U-236,** because the alpha energy peaks are nearly identical. However, for the November **2001** sample, the analytical and measurement conditions were optimal, and the analyst was able to discriminate and quantify **U-235 and U-236.**

The detections and existence of uranium at this lysimeter location are substantiated by the fact that: (1) the uranium isotopes also were detected in the laboratory-generated duplicate at concentrations similar to the original analysis results, **(2)** the November **2001** and April **2002** results are comparable, and **(3)** shipping records show highly enriched uranium waste from weapons manufacturing was disposed of at this location. The **U-238** and **U-235** ratios associated with both sampling events, as well as the presence of **U-236,** indicate the source of uranium to be anthropogenic with a slight **U-235** enrichment. The measured uranium results are consistent with the solubility limits for their respective oxides. The measured isotopic uranium results (pCi/L) converted to mass (mg/L) show the solubility to be inline for a pH between 7 and 8. The 741-08-L1 lysimeter also was sampled April 2002; however, the sample volume was insufficient to perform isotopic uranium analyses.

3.7.5 Other Radionuclide Contaminants

The waste zone soil moisture samples collected in FY 2002 from Lysimeters 741-08-L1 and DU-14-L1 were analyzed for 21 gamma-emitting radionuclides with no positive detections. Lysimeter DU-14-L1 yielded only 2 mL of water, which was an insufficient volume to perform any other type of radionuclide analyses.

4. TENSIOMETERS

4.1 Introduction

Sixty-six drive-point tensiometers were designed by the INEEL, constructed by Northeast Manufacturing of Meridian, Idaho, and installed using the INEEL sonic drill. The tensiometer design and operation is described in *OU 7-13/14 Integrated Probing Project OU 7-13/14 Tensiometer Probe Design* (Grover 2001). The tensiometers have two pressure sensors used to measure the gas pressure and the liquid fluid pressure within the sediments and waste products. Instruments were installed at three target depths: at the top of the waste, at the midpoint within the waste, and in sediments beneath the waste. Tensiometers are connected to Campbell Scientific data loggers, queried on a two-hour basis, and data are transmitted to a computer at the RWMC. These data are posted on the JOBHE2 shared directory on a daily basis. The data were imported into Excel spreadsheets and plotted. The sensors have undergone the initial INEEL Standards and Calibration Laboratory calibration and will be field validated, so all data presented in this report are conditional. Data evaluation information presented in this report is based on evaluation of field data from the instruments.

The direct push tensiometers were constructed and installed at the SDA of the RWMC in fall of 2001. The data loggers were installed and instruments connected so that data collection commenced in January 2002 for most of the instruments. Field maintenance was conducted to initially fill the instruments with water and begin data collection. In April, an initial evaluation of the soil water potential and soil gas pressure data suggested that most of the soil gas pressure sensors were providing reasonable data but that most of the soil water potential tensiometers were not providing reasonable data. Several field-testing activities were followed by evaluation of the resultant data to evaluate the potential problems and detail the field solutions to activate the tensiometers. Testing procedures were developed (TPR-1763), approved for use, and conducted in the field to isolate the potential reasons for not providing representative data. These field activities isolated and corrected the sources of the problem for many of the instruments. Several reports were produced detailing potential problems on the suite of instruments (Appendixes D, F, G, and H). Evaluation of field data and field testing suggests several field activities are required to get the remaining instruments operational and to qualify the data (Appendix G).

4.2 Direct Push Tensiometer Instrumentation

Direct push tensiometers are instruments that yield water-potential data and soil gas pressure at specified depths. The direct push tensiometer has a drive point and a sealed porous stainless steel chamber filled with water that is installed at a specified depth. The chamber is connected to a second upper water chamber that has two lines that extend to land surface. The lines have normally closed valves immediately above the lower water chamber, isolating the upper chamber from the water in the water lines, for refilling the lower chamber with water. Pressure transducers (absolute pressure) sense the soil water pressure in the surrounding sediment through the porous stainless steel membrane, and a second pressure transducer measures the gas pressure in the soil. A third line extends to land surface that, when combined with the other lines and valves, allows the sensors to be tested relative to a reference pressure in the field.

In operation, a measured volume of water is placed in the upper water chamber and then the lower water chamber by opening a combination of valves. The lower chamber is filled with water from the upper water chamber and then sealed. Water in the porous **SS** cup then moves into or out of the formation in response to soil water changes in the soil. Water moving from the initial atmospheric pressure in the porous cup to a subatmospheric (negative) pressure in the soil (underunsaturated conditions) creates a partial vacuum in the porous cup that is sensed by the lower pressure transducer. A data logger connects to the pressure transducer for continuous monitoring and data storage. Hubbell and Sisson (1998) and the

U.S. Department of Energy (DOE 2002) present a description of standard tensiometer construction, operation, and maintenance in reports.

Instruments were installed at multiple depths: above the waste, within the waste, and below the waste in underlying sediments. Instruments were delivered to the SDA with the porous stainless steel membrane unattached; the porous stainless steel was wetted before insertion, assembled at the drill site, and then installed using the sonic driving technique. Probes were installed by driving using the drill rig down pressure until consolidated sediments were encountered at about 2 ft. Then, the sonic drive head was activated, and the probe was sonically pushed to a specified depth.

Figure A-5 shows the locations of the wells containing the tensiometers. Sixty-six direct push tensiometers were installed and instrumented as part of the WAG 7 OU 7-13/14 hydrologic characterization activities (Salomon 200 1).

4.2.1 Soil Gas Pressure Measurements

The upper pressure sensors measure the soil gas pressure relative to absolute pressure. The measurement is obtained from the upper pressure sensor that obtains measurements from openings located a few inches above the soil water potential measurement location. If the soil gas is in direct pneumatic connection with the atmospheric pressure by way of the soil, the readings should track the barometric pressure. Deviations (lag) and diminished amplitude signals from the barometric pressure are anticipated since some sensors will be contained in materials that do not allow the immediate transmittal of atmospheric pressure to the point of measurement. Raw data from the sensors are presented in Appendix F along with a short description relating to their operational characteristics.

4.2.2 Soil Water Potential Measurements

The lower pressure sensor measures the soil water potential relative to absolute pressure. The sensor measurement from the soil gas pressure (upper sensor) is subtracted from the soil water potential sensor (lower sensor) to obtain the soil water potential relative to atmospheric pressure (standard measurement technique). The sensor is located beneath the lower water chamber, and so it will provide accurate water potential measurements until there is air entry through the porous membrane. If the membrane is not saturated, the pressure will track the atmospheric pressure. These readings are plotted in the Excel spreadsheets in Appendix A along with a brief description and evaluation of the data.

Water potential is a means of measuring the relative energy state of water to evaluate the status and movement of water. Under h1ly saturated conditions, water is at hydrostatic pressures greater than atmospheric pressure, and water potential is positive. Under unsaturated conditions, capillary and adsorptive forces hold water in the soil matrix. In this unsaturated state, water potential is negative by convention because the hydrostatic pressures are less than atmospheric pressures. The drive-point tensiometer measurements are expressed in terms of an equivalent head of water, such as the centimeters of water units used in this report (where 1,015 cm is equivalent to 14.7 psi or one atmosphere pressure). For a homogeneous medium, the higher (or less negative) the water potential measurement, the greater the moisture content of the material being measured. Positive water potentials indicate saturated conditions while negative water potentials indicate unsaturated conditions.

Water potential data are used to determine the status of water in sediment or waste (i.e., whether the material is saturated or unsaturated and can be used to determine hydraulic gradients [direction of moisture flow] if multiple instruments are installed at a given location). The water potential is one of the state variables used to characterize moisture flow and transport in the vadose zone. For a homogeneous medium, the more negative the water potential, the dryer the medium. Decreasing water potentials indicate decreasing water content in the medium, and conversely, increasing water potentials indicate increasing water contents. The changes in water content can be determined using soil moisture characteristic curves for the materials. Soil moisture characteristic curves define the relationship between the soil water potential versus water content and are determined from laboratory tests.

4.2.3 Sensor Qualification Criteria

The tensiometers contain two 15-psia Sensotec pressure transducers. Sensors were calibrated at the INEEL Standards and Calibration Laboratory before final assembly of the devices. The required specification was that the sensors should be within ±0.2% of full-scale or ± 5 cm water pressure over the range of measurements. All of the transducers that were placed in the field met the specified standard. Calibration sheets for each sensor are available from the INEEL Standards and Calibration Laboratory.

Once the probes are placed in the ground, the contained sensors cannot be removed for laboratory calibration, but they can be field tested to validate their operation to specifications. The pressure sensors are placed under moderate to very high stresses during installation from the sonic insertion technique. The probe insertion technique used a combination of the direct push technique, using the drill rig down pressure to advance the probe, and the sonic technique where the drill string and probe are vibrated to assist rapid penetration. The vibration from the sonic drilling has the potential to alter the calibration, so the instruments were designed to allow validation of the measurements by performing field testing procedures. Field validation procedures are detailed in TPR-1763 with field data recorded on INEEL Form 416.33.

Field validation procedures were tested on three sensors (DU-10, T-1, and -2 and -3) and to validate the operation of the sensors. The data from the test are attached as Appendix E. Data indicated that the three sensors evaluated exceed the specified operational requirements in the upper range but meet the requirements over the majority of the range.

4.3 Accuracy and Usefulness of Data

The data validation was conducted using the following logic. To be hlly qualified and certified, the sensors must go through the following steps for the data to be hlly useable:

1. Sensors are calibrated by the INEEL Standards and Calibration Laboratory.

2. Following installation, the sensors operation is field validated. A known range of pressures is applied to the sensor and checked to the output response recorded on the data logger and ultimately in the database. Data may be used from the sensors, even if the sensor is out of specification, if the data from the validation process can be used to correct the data.

The initial Step 1 was performed on all the sensors, but the second step has not been conducted Thus, data are conditional at this time. Data should continue to be collected and may be hlly useable following the field validation process.

4.3.1 Data Evaluation

This evaluation is based on conditional data as discussed in the previous section. Results of the evaluation of the data are contained in Appendix A, and recommendations for field activities to either further evaluate or correct the data are presented in Appendix B. During the activation process (i.e., filling the instrument with water), many sensors did not respond as anticipated, so the data were plotted and evaluated to determine the most logical potential problems.

There are a variety of potential problems suggested by the response of the pressure sensors from field activities. Note that these proposed solutions and projected problems are based on just the response of the sensors recorded in the database and that real-time field testing and response are critical to ensure proper operation. The mechanical and electrical problems encountered in the field included but were not limited to:

- Tubing was initially reversed on some of the tensiometers preventing proper filling of the water reservoirs
- Pinched tubing at the cap prevented placing water into the tensiometer
- Spool valves required higher pressures to activate
- Freezing of the water in the tubing may have prevented filling with water
- Pressure sensors over stressed during installation
- Wiring problems, including:
    - Sensor not connected to logger (-253-cm signal)
    - Intermittent or poor connection to logger
    - Reversed wiring between the upper and lower sensors
- Data logger problems (programming and power supply [i.e., battery])
- Poor or intermittent communication with the computer database
- Air leaks into the lower water reservoir, including loose fittings and seals or a partially saturated porous stainless steel membrane.

The overall tensiometer design, based on field data, appears to be hlly functional; however, the complexity of the instrument combined with the high initial field requirements to get the instruments running and the sensors validated have been time consuming.

4.3.2 Results and Discussion

The field validation process has not been completed on the sensors in the drive-point tensiometers in FY 2002, so the data interpretation in this section will be conditional based on unvalidated data. The soil gas pressure and calculated water potential data over time for each borehole are presented in Appendix A from the start of monitoring in January 2002 through August 2002.

Most of the soil gas sensors are functional, indicating that they are tracking the soil gas pressure at the point of measurement. Those data indicate that most sensors are in materials that are in direct pneumatic connection with the atmosphere. Other sensors appear to be offset from atmospheric pressure and others with delayed responses (lag). The sensors are all referenced to absolute pressure. Data from the sensors are presented in Appendix A by site locations with comments included. Barometric pressure data obtained from the National Oceanic and Atmospheric Administration collected at the RWMC are included for reference in Appendix A.

Figure 26 presents the calculated soil water potential response from four direct push tensiometers The soil gas pressure is subtracted from the lower pressure sensor response to obtain this measurement relative to atmospheric pressure. These tensiometer measurements are from instruments located beneath the waste.

Tensiometer 743-03 (T3) at 19.3 ft shows that before filling with water, it was reading about -10 cm, suggesting the sensor was reading properly. Following filling with water, the initial equilibration with the surrounding sediment was very slow, taking about 50 days to reach the –350-cm water potential. The upward spikes in the data indicate testing and maintenance on the sensor. The second spike indicates that when the instrument is refilled with water, it will not require reequilibration with the surrounding sediments. Data, once the instrument came into equilibrium, indicate a wetting trend of about 25 cm over the period of record (this trend is related to the response of the gas pressure). It also indicates that despite the relatively dry field conditions, the sensor can operate for extended time periods without refilling the lower water chamber. The water potential of –350 cm indicates a low water potential at this location. It would be anticipated that lysimeters located near this location would have a sufficiently low-hydraulic conductivity so that water samples would be difficult to obtain.

Sensor MM1-1 (T3) at 16.3 ft deep started with initial readings about +50 cm, suggesting that the calibration offset may have been impacted during installation process. The sensor equilibrates very slowly over a 70-day period, suggesting a poor hydraulic contact or low-permeability surrounding material. The sensor data indicate an equilibrated reading of about –95 cm. It is difficult to determine the exact time the sensor equilibrated since the soil water potential trend in the native sediments is not known before insertion of the instrument. If the sediment is drying, longer equilibration times would be indicted than if the sediment was wetting as seen in the previous instrument. Air enters the tensiometer very rapidly on 9/21 suggesting that maintenance may have been performed on the instrument, but the readings do not decline indicating a potential problem with the instrument such as a valve not closing. The higher soil water potential (less negative) reading at this location suggests that if a lysimeter had been installed at this location, it would be able to yield water samples.

Sensor MM2-1 (T3) at 16.8 ft deep started with initial readings about +120 cm, suggesting that the calibration offset may have been impacted during installation process. The sensor equilibrated quickly over a 13-day period, suggesting a relatively good hydraulic contact. The sensor data indicate an initial equilibrated reading of about –85 cm. The water potential then starts decline to less than –110 cm. The higher soil water potential reading at this location suggests that if a lysimeter had been installed at this location, it would be able to yield water samples.

Sensor 741-08 (T3) at 20.7 ft deep started with initial readings near zero and probably was not impacted during the installation process. The sensor equilibrates over about a 70-day period, suggesting a poor hydraulic contact or low-permeability material around the sensor. The sensor data indicate an equilibration to about –80 cm then slowly drying to about –110 cm. The higher soil water potential readings suggest a lysimeter at this location should yield water samples.

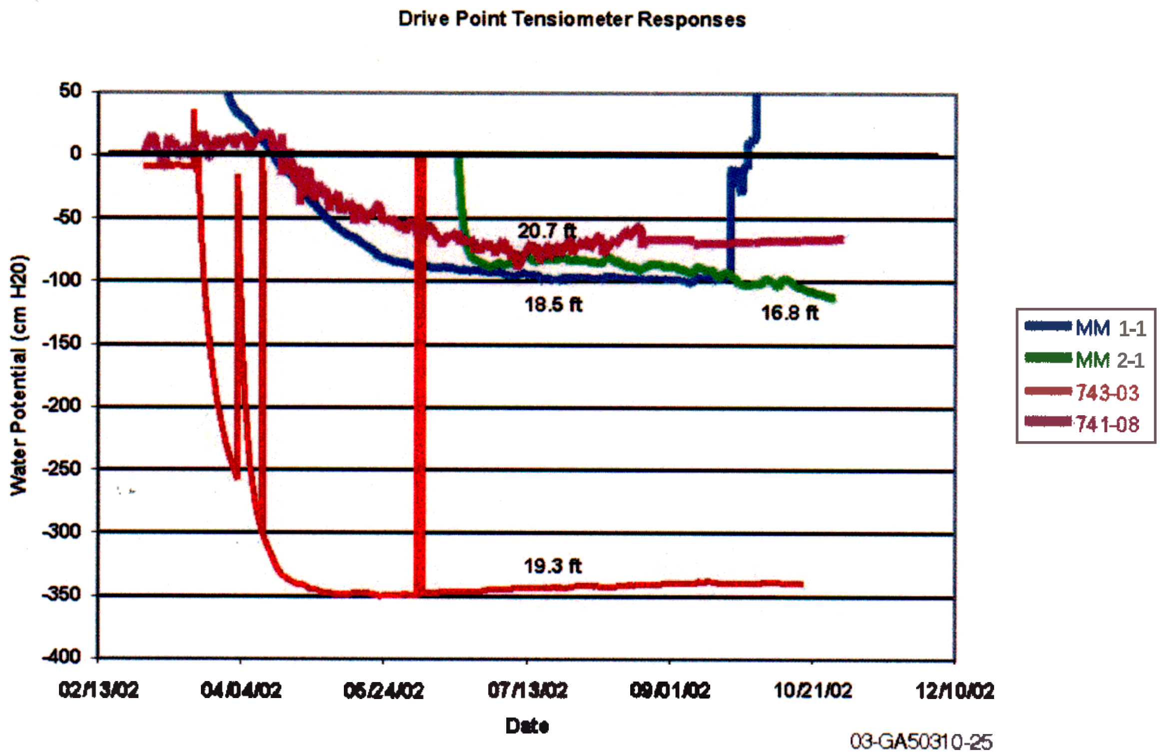

Figure 26. Soil water potential measurements from selected direct push tensiometers.

4.4 Recommendations

Each tensiometer should have proper field testing and sensor validation performed. The field testing should be performed to validate and correct problems relating to wiring and data logger connections to ensure that the sensors are working properly and the spool valves are operational (activating the tensiometer). Each sensor should be field validated using procedures outlined in TPR-1763. Real-time feedback in the field is necessary to properly evaluate the instruments. This evaluation will determine which instruments are fully functional and which require additional work or abandonment.

The potential for dewatering of the porous stainless steel and damage to the instrument (loosening of fittings, kinking of tubing, and breaking of seals) during installation should be evaluated. Alternate or modifications to the drilling technique should be considered that reduce the installation stresses. The sonic drilling technique may dewater the porous stainless steel during installation because of the high acceleration (up to 500 g). If the porous stainless membrane was dewatered, it might require several fillings or specialized refilling procedures to ensure full wetting of the porous stainless steel. The fundamental tensiometer design, upon which the drive point tensiometer was based, will work as evidenced by Sisson et al. (2002) where data are presented from less complex tensiometers that have been in continuous operation for several years.

The tensiometer design is complex. The design's complexity makes the instrument difficult to maintain and ensure it is collecting data properly in the field (for filling and initial field validation of the sensor). The sonic installation places the instrument and contained pressure sensors under high stresses that may shift calibration or damage the sensor. A simpler design with a replaceable pressure sensor should be considered if more tensiometers are installed. There is a design where the drive tip is installed and then either a pressure sensor or sampling apparatus is placed in the apparatus to use it as a tensiometer or suction lysimeter.

5. SOIL MOISTURE PROBE

5.1 Introduction and Status

The Vertek soil moisture and resistivity (SMR) probe was used to measure resistivity, moisture content, and temperature. The probes were obtained from Applied Research Associates and are an existing commercial off-the-shelf unit. Vertek is the manufacturing arm of Applied Research Associates. The soil moisture probe consists of a series of electrode rings separated by insulated rings. The outer set of rings measures resistivity, and the inner set of rings measures capacitance to calculate soil moisture. Soil temperature is measured with a diode. The probe specifications are described in *Operable Unit 7-13/14 Integrated Probing Project Soil Moisture Instrumented Probe* (INEEL 2001). The locations of the SMRs are shown in Figure A-4.

Seventy-eight soil moisture resistivity probes were installed. Fifty-seven probes were hnctioning at some time during FY 2002. Thirteen probes are not hnctioning, and eight probes record only their probe identifiers. Data collection generally started around the end of January for the SMRs, and data collection was on a 2-hour interval. At the end of the FY (September 2002), probe data were not being recorded from Data Logger Stations DU1 and DU2. Therefore, data were not being recorded at an additional 25 SMRs, but presumably the SMRs at DU1 and DU2 will function once the batteries at the data stations are replaced. In addition, bad data points were frequent, and data were not collected from some stations for periods greater than a week. For example, data were not collected for the probes at DU1 from June 5 till June 18, and a 44-day gap in data collection occurred at MM3 from July 23 to September 5, 2002. Data have not been collected for any of the probes associated with the DU2 station since July 5, 2002. Probe status is summarized in Table 14.

5.2 Probe Calibration

Soil moisture probes were calibrated using moisture extremes by taking a reading in air and then in water. Once driven into the subsurface, the probes can not be recalibrated without the probe being pulled back up. Because the probes were not calibrated to the actual soil conditions, the reported moisture contents by the probes should be viewed as relative values rather than absolute values. In addition, metal objects near or next to the probes can affect the moisture content determined by the SMRs.

Table 14. Probe status.

Probe Station	Probe ID		Probe Cluster	Depth	Moisture		Temperature		Resistivity	
					Status 5/30/2002	Status 10/1/2002	5/30/2002	Status 10/1/2002	5/30/2002	Status 10/1/2002
741	SMR-266	266	741-08-M1	19.86 ft	W	W	W	W	W	W
	SMR-268	268	741-08-M1	11.5 ft	W	W	W	W	W	W
	SMR-267	267	741-08-M1	4.14 ft	W	W	W	W	W	W
743	SMR-217	217	743-18-M1	6.47 ft	W	W	W	W	W	W
	SMR-235	235	743-03-M1	3.36 ft	W	W	W	W	W	W
	SMR-237	237	743-03-M1	19.09 ft	W	W	W	W	W	W
	SMR-247	247	743-08-M1	6.6 ft	W	W	W	W	W	W
	SMR-250	250	743-08-M1	13.9 ft	W	W	W	W	W	W
	SMR-251				***Nw***	***Nw***	***Nw***	***Nw***	***Nw***	***Nw***
DU-1	SMR-288	288	MM4-5b	4.4 ft	W	SP	W	SP	W	SP
	SMR-277	277	DU-1O-MD	6.72 ft	W	SP	W	SP	W	SP
	SMR-271	271	DU-10-m2	6.64 ft	W	***Nw***	W	***Nw***	W	***Nw***
	SMR-264	264	DU-1O-M1	9.25 ft	W	SP	W	SP	W	SP
	SMR-263	263	DU-10-M3	3.97 ft	W	SP	W	SP	W	SP
	SMR-257	257	MM4-4B	4.17 ft	W	SP	W	SP	W	SP
	SMR-256	256	MM4-4B	8.72 ft	W	SP	W	SP	W	SP
	SMR-255	255	MM4-3C	4.8 ft	W	SP	W	SP	W	SP
	SMR-243	243	MM4-3B	6.18 ft	W	SP	W	SP	W	SP
	SMR-239	239	MM4-5B	9.75 ft	W	SP	W	SP	W	SP
	SMR-234	234	MM4-5	13.88 ft	W	SP	W	SP	W	SP
	SMR-230	230	MM4-4	10.28 ft	W	SP	W	SP	W	SP
	SMR-218	218	MM4-3	9.11 ft	W	SP	***Nw***	***Nw***	W	SP
	SMR-274				***Nw***	***Nw***	***Nw***	***Nw***	***Nw***	***Nw***
DU-2	SMR-286	286	MM4-1B	14.67 ft	W	***Nw***	W	***Nw***	W	***Nw***
	SMR-287	287	MM4-1B	6.3 ft	W	***Nw***	W	***Nw***	W	***Nw***

Table 14 (continued)

Probe Station	Probe ID		Probe Cluster	Depth	Moisture Status 5/30/2002	Moisture Status 10/1/2002	Temperature 5/30/2002	Temperature Status 10/1/2002	Resistivity 5/30/2002	Resistivity Status 10/1/2002
	SMR-280	280	DU-14-M1	4.47 ft	W	NW	W	NW	W	NW
	SMR-278	278	DU-14-M1	9.83 ft	W	NW	W	NW	W	NW
	SMR-276	276	DU-14-M1	15.2 ft	W	NW	W	NW	W	NW
	SMR-272	272	MM4-1D	16.72 ft	W	NW	W	NW	W	NW
	SMR-270	270	DU-08-M1	17.86 ft	W	E	W	E	W	E
	SMR-269	269	DU-08-M1	11.5 ft	W	E	W	E	W	E
	SMR-223	223	MM4-2	17.39 ft	W	E	W	E	W	E
	SMR-233				NW	E	NW	E	NW	E
	SMR-265				NW	E	NW	E	NW	E
MM1	SMR-238	238	EM1-2a	6.0 ft	3	3	3	3	3	3
	SMR-212				NW	NW	NW	NW	NW	NW
	SMR-213				NW	NW	NW	NW	NW	NW
	SMR-227				NW	NW	NW	NW	NW	NW
MM2	SMR-246	246	EE2-3B	1.67 ft	W	W	W	W	W	W
	SMR-241	241	EE2-1B	12.51 ft	W	W	W	W	W	W
	SMR-231	231	EE2-1	16.0 ft	W	W	W	W	W	W
	SMR-229	229	MM2-3B	6.98 ft	W	W	W	W	W	W
	SMR-224	224	EE2-2	10.78 ft	3	3	3	3	3	3
	SMR-222	222	EE2-2B	9.14 ft	3	3	3	3	3	3
	SMR-221	221	EE2-1B	7.25 ft	3	3	3	3	3	3
	SMR-220	220	EE2-2B	4.0 ft	3	3	3	3	3	3
	SMR-215	215	EE2-3	3.05 ft	3	3	3	3	3	3
EM3	SMR-254	25d	EM33a	7.46 ft	3	3	3	3	3	3
	SMR-253	25[illegible]	EM3-1a	7.62 ft	3	3	3	3	3	3
	SMR-252	252	MM3-2B	6.96 ft	W	W	W	W	W	W
	SMR-245	245	MM3-1C	4.47 ft	W	W	W	W	W	W

Table 14. (continued)

Probe Station	Probe ID		Probe Cluster	Depth	Moisture Status 5/30/2002	Moisture Status 10/1/2002	Temperature 5/30/2002	Temperature Status 10/1/2002	Resistivity 5/30/2002	Resistivity Status 10/1/2002
	SMR-244	244	MM3-3B	13.82 ft	W	W	W	W	W	W
	SMR-242	242	MM3-1	9.69 ft	W	W	W	W	W	W
	SMR-225	225	MM3-3	17.0 ft	W	W	W	W	W	W
	SMR-216	216	MM3-2C	3.97 ft	W	W	W	W	W	W
	SMR-210	210	MM3-2	8.53 ft	W	W	W	W	W	W
Pit5-4	SMR-289	289	Pit5-4-MB	2.81 ft	W	W	W	W	W	W
	SMR-285	285	Pit5-4M	10.16 ft	W	W	W	W	W	W
	SMR-279	279	Pit5-4-MB	8.18 ft	W	W	W	W	W	W
Pit5-T	SMR-282	282	Pit5-W1-M	10.24 ft	W	W	W	W	W	W
	SMR-291	291	Pit5-W1-MB	8.22 ft	W	W	W	W	W	W
	SMR-290	290	Pit5-W1-MB	2.85 ft	W	W	W	W	W	W
SVR-20	SMR-258	258	SVR-20M	17.44 ft	W	W	W	W	W	W
	SMR-259	259	SVR-20-MB	13.79 ft	W	W	W	W	W	W
	SMR-260				***Nw***	NW	***Nw***	***Nw***	NW	***Nw***

W = working, in some cases the data are questionable

NW = not working

SP = station problem, probes may work after station battery is replaced

5.3 Summary of Soil Moisture and Resistivity Data Trends

Graphs of the moisture, temperature, and resistivity data for the functioning SMRs are shown in Appendix L. Trends in the moisture, temperature, and resistivity data are described below and summarized in Table 15.

5.4 Moisture Data

The moisture data were plotted and examined to evaluate trends in the data and the potential impact of snowmelt on soil moisture content. Because the SMR probes are deeper than 2 ft, summer rain events are not expected to influence soil moisture contents. Neutron access tube monitoring at the **SDA** and at Central Facilities Area has shown that the spring snowmelt event constitutes the most significant infiltration event. The trends and changes in moisture content for the SMRs are addressed by the probe cluster below, except for SVR-12. None of the SMRs are functioning at SVR-12. The moisture monitoring results are as follows:

- At DU-08, moisture movement has not been observed at depths of 11.5 or 17.86 ft. The shallow SMR is not functioning at this location.

- At DU-10, there is an indication of moisture movement at 3.97 and 9.25 ft but no indication at 6.64 or 6.72 ft. The increase in moisture content is consistent with the timing of the spring snowmelt. Soil and moisture resistivity Probe Number 263 at a depth of 3.97 ft shows approximately 6.5–7.5% increase in moisture content while the SMR at 9.25 ft shows about 2.5-3% increase in moisture content.

- At DU-14, there is some indication of moisture movement at a depth of 4.47 ft and possibly at 15.2 ft but not at a depth 9.83 ft. Data from this cluster have not been collected since early July.

- At SVR-20, the two functioning SMRs do not appear to show any trends in the data.

- The middle SMR at a depth of 8.22 ft in the Pit 5-T probe cluster showed an increase in moisture content of 4–5%, but the SMRs at depths of 2.85 or 10.24 ft did not. The shallow moisture probe, SMR 290, showed a response that is the reverse of what is expected with moisture decreasing until midJuly, and then increasing after midJuly.

- At Pit 5-4, a minor moisture increase was observed at 10.16 ft but not at depths of 8.18 or 2.81 ft. The increase at 10.16 was slight (approximately 3% moisture content). Although the timing of the increase is near the spring snowmelt, the small change might be caused by instrument drift.

- At 743-03, there is no indication of moisture movement in the deep (19.09 ft) SMR, and the middle SMR is not functioning. The shallow SMR at 3.36 yields the reverse of what should be happening (that is, it decreases in moisture content until July, then starts increasing again).

- At 743-08, there is a minor indication of moisture movement at depths of 6.6 and 13.9 ft. Both SMRs show modest increases in moisture content of about 2–3%. The 6.6-ft depth probe, SMR 247, starts increasing in late April and gradually increases until late September. The deep probe starts increasing in late May and increases until early October.

- At 743-18, only the SMR at a depth of 6.47 ft is working, and there is not definite indication of moisture movement at this depth.

Table 15. Summary of soil moisture and resistivity monitoring.

				Moisture Content				Temperature			
Probe Station	Probe ID	Probe Cluster	Depth	Shows Increase	Date Started	Peak Date	Increase[a]	Minimum	Maximum	Range (°C)	
741	SMR-266	741-08-M1	19.86 ft	No				Mid-June	Mid-November	8	12
	SMR-268	741-08-M1	11.5 ft	Yes	Early April	Late June	1.5	Late April	Early October	8	16
	SMR-267	741-08-M1	4.14 ft	No				Mid-March	Late August	3	19
743	SMR-217	743-18-M1	6.47 ft	Maybe	Late April	Late August	2 to 3	Mid-March	Early September	5	20
	SMR-235	743-03-M1	3.36 ft	No				Late March	July	3	22
	SMR-237	743-03-M1	19.09 ft	No				Early June	Early November	25	28
	SMR-247	743-08-M1	6.6 ft	Yes	Late April	Mid-October	2 to 3	Late March	Early September	5	22
	SMR-250	743-08-M1	13.9 ft	Yes	Late May	Late October	2 to 3	Mid-May	Late October	15	22
DU-1	SMR-277	DU-10-MD	6.72 ft	No				Early April	Late August	3	19
	SMR-271	DU-10-M2	6.64 ft	No				Early April	NW	3	NW
	SMR-264	DU-10-M1	9.25 ft	Yes	Late April	Early September	2.5 to 3	Early April	Mid-September	6	15
	SMR-263	DU-10-M3	3.97 ft	Yes	Late March	Early September	6.5 to 7.5	Mid-March	Late July	0	20
	SMR-257	MM4-4B	4.17 ft	Yes	Late March	Early September	8.5 to 9.5	Mid-March	Late July	0	22
	SMR-256	MM4-4B	8.72 ft	Yes	Mid-April	Mid-August	15 to 18	Early April	Mid-September	6.5	16
	SMR-230	MM4-4	10.28 ft	No[b]				Mid April		4	
	SMR-255	MM4-3c	4.8 ft	Yes	Mid-April	Early September	8 to 9	Late March	Mid-August	2	20
	SMR-243	MM4-3B	6.18 ft	Yes	Early April	Early September	16 to 17	Late March	Late August	3	19
	SMR-218	MM4-3	9.11 ft	Yes	Mid-April	Late August	4 to 5	NW	NW		
	SMR-239	MM4-5B	9.75 ft	No				Early April	Mid-September	7	16
	SMR-234	MM4-5	13.88 ft	No				Early May	October	5	10
	SMR-288	MM4-5b	4.4 ft	Yes	Early April	Late August	4 to 5	Late March	Late July	1	20
DU-2	SMR-286	MM4-1B	14.67 ft	No		**ND**		**ND**	**ND**		
	SMR-287	MM4-1B	6.3 ft	Yes	LateMarch	**ND**		**ND**	**ND**		
	SMR-272	MM4-1D	16.72 ft	No		**ND**		**ND**	**ND**		
	SMR-280	DU-14-M1	4.47 ft	Yes	Early April	**ND**		**ND**	**ND**		
	SMR-278	DU-14-M1	9.83 ft	No		**ND**		**ND**	**ND**		

Table 15. (continued)

				Moisture Content				Temperature			
Probe Station	Probe ID	Probe Cluster	Depth	Shows Increase	Date Started	Peak Date	Increase[a]	Minimum	Maximum	Range (°C)	
	SMR-276	DU-14-M1	15.2ft	Maybe	Late April	**ND**		**ND**	**ND**		
	SMR-270	DU-08-M1	17.86ft	No		**ND**		**ND**	**ND**		
	SMR-269	DU-08-M1	11.5ft	No		**ND**		**ND**	**ND**		
	SMR-223	MM4-2	17.39ft	No		**ND**		**ND**	**ND**		
MM1	SMR-238	MM1-2B	6.0ft	Yes	Late March	Late June, October	4	Mid-March	Early August	1	21
MM2	SMR-246	MM2-3B	1.67ft	Yes	Late March	Mid-May	14 to 15	Late March	Mid-July	0	30
	SMR-215	MM2-3	3.05ft	Yes	Late March	Mid-July	5 to 6	Late March	Mid-July	-5	21
	SMR-229	MM2-3B	6.98ft	Yes	Early April	Mid-September	3.5 to 4.5	Late March	Late August	1	15
	SMR-241	MM2-1B	12.51ft	No				Late April	Early October	9	16
	SMR-231	MM2-1	16.0ft	Yes	Early April	Mid-July	3	Late May	Late October	5	10
	SMR-221	MM2-1B	7.25ft	Yes	Early April	Mid-August	5 to 6	Late March	Late August	-7	8
	SMR-224	MM2-2	10.78ft	Yes	Late May	Late October	2 to 3	Mid-April	Late September	2	11
	SMR-222	MM2-2B	9.14ft	Yes	Mid-April	Mid-October	6.5 to 7.5	Early April	Early September	0	14
	SMR-220	MM2-2B	4.0ft	No				Late April	Mid-July	-3	19
MM3	SMR-254	MM3-3B	7.46ft	Yes	Early April	Early September	4 to 5	Late March	August	1	22
	SMR-244	MM3-3B	13.82ft	Yes	Mid-April	Late September	1.5 to 1.8	Early April	Late August	5	16
	SMR-225	MM3-3	17.0ft	No				Late April	Late October	5	9
	SMR-253	MM3-1B	7.62ft	Yes	Mid-April	Mid-September	3.5 to 4.5	Early April	August	4	20
	SMR-245	MM3-1C	4.47ft	Yes	LateMarch	August	13 to 15	Mid-March	August	2	22
	SMR-242	MM3-1	9.69ft	Yes	Late April	Early September	5 to 6	Early April	August	3	19
	SMR-252	MM3-2B	6.96ft	No				Early April	August	4	19
	SMR-216	MM3-2C	3.97ft	Yes	Early April	August	5 to 6	Late March	Early August	-2	20
	SMR-210	MM3-2	8.53ft	Yes	Mid-April	Mid-September	5 to 6	Early April	August	0	13
Pit5-4	SMR-289	Pit5-4-MB	2.81ft	No				Early March	Mid-July	0	27
	SMR-285	Pit5-4M	10.16ft	Yes	Late March	Late July	3	Early April	Mid-September	6	19

Table 15. (continued)

				Moisture Content				Temperature			
Probe Station	Probe ID	Probe Cluster	Depth	Shows Increase	Date Started	Peak Date	Increase[a]	Minimum	Maximum	Range (°C)	
	SMR-279	Pit5-4-MB	8.18 ft	No				Mid-March	Early September	5	20
Pit5-T	SMR-282	Pit5-W1-M	10.24 ft	No				Mid-April	Mid-September	5	15
	SMR-291	Pit5-W1-MB	8.22 ft	Yes	Late May	Early October	4 to 5	Late March	Mid-September	**6**	17
	SMR-290	Pit5-W1-MB	2.85 ft	No				Early March	Mid-July	0	25
SVR-20	SMR-258	SVR-20M	17.44 ft	No				Early June	November	7	11
	SMR-259	SVR-20-MB	13.79 ft	No				Early May	Late October	7	14

a. Increase in percent moisture content

b. Moisture content reading above 100%

ND = not determined because of either station problem or probe problem

NW = not working

- At 741-08, the SMR at 11.5 ft shows a modest increase in moisture content of about 1.5%. The shallow (4.14 ft) and deep (19.86 ft) SMRs do not show a distinct trend. The shallow SMR shows anomalous moisture content spikes in late July and in mid-September, but there are no precipitation events that could cause this change, so it looks like a shift in instrument response rather than an actual increase in moisture content.

- At MM2-1, the shallow (7.3 ft) and deep (16.9 ft) probe showed an increase in moisture content; however, the intermediate depth, 12.5 ft, probe did not. The moisture increase in the shallow probe started in late March, and the deep probe started soon after in early April. The increase in moisture content in the shallow probe was about twice that of the deep probe.

- At MM2-3 and MM4-3, all of the SMRs show an increase in moisture content coinciding with the spring snowmelt. The shallowest SMR at MM2-3 showed the largest increase in moisture content, but at MM4-3, the middle SMR had the largest increase in moisture content.

- The moisture monitoring results at MM2-2 showed increasing moisture at the intermediate and deepest SMR, but the shallowest SMR did not show a trend.

- At MM4-1 and MM4-5, only the shallowest SMR at each cluster shows an increase in moisture corresponding to the spring snowmelt event.

- Only the deep SMR Probe Number 223 was hnctioning at MM4-2. This SMR did not show any indications of moisture movement. However, data have not been collected for this SMR since early July.

5.5 Summary of Temperature Data

Temperature data for the SMRs generally reflected seasonal trends with a time lag to surface air temperatures depending on the depth of the SMR. Shallow probes, less than 6 ft, generally have a minimum temperature in early to late March and a maximum temperature in midJuly to late August. Deep probes, greater than 13 ft in depth, generally have a low temperature in mid-May to early June and a maximum temperature in October to early November. Probes between 5 and 13 ft in depth exhibit temperature variations between the shallow and deep probes. The temperature data at the 741-08, MM2-1, MM2-2, MM2-3, DU-10, MM4-4, MM4-3, and MM4-5 clusters showed the typical pattern of surface temperature changes lagging with depth.

The range of temperature fluctuations is also depth dependant. The largest temperature swings are in the shallow probes (less than 4 ft deep), and the smallest temperature changes are in the deepest probes (more than 15 ft deep). The largest temperature change of approximately 30°C occurred in SMR 246 (1.7 ft), and the smallest temperature range of 4°C occurred in probes below the depth of 17 ft.

Temperature changes mirrored moisture content changes at some locations, but the reverse was true at other locations. At several SMRs, temperature changes mirrored changes in moisture content, so that decreases in temperature matched decreases in moisture content, and increases in temperature coincided with increases in moisture content. Several of the probes at DU-1, including SMRs 264, 263, 257, 256,255,243, and 288, showed a positive correlation between temperature change and change in moisture content. The temperature data for the two probes at 743-08 also mirrored changes in moisture content. In contrast to the above probes, two SMRs, SVR-20 and SMR 290, at Pit5-T showed a negative correlation with temperature.

At some SMRs, moisture changes did not show any relationship to temperature changes. For instance, the SMR and temperature data did not show any relationship for the three SMRs for the Pit5-4 station or SMR 282 at Pit5-T.

5.6 Summary of Resistivity Data

The purpose of collecting the resistivity data is to aid in determining the moisture content. The resistivity data were not used to calculate moisture contents for this annual report. It is anticipated that in the future this would be done after the probes have been tested experimentally in a laboratory setting.

5.7 Issues

There are several concerns regarding probe station performance. Batteries for the data stations fail too frequently even though they are designed to have **336** hours of reserve. The battery requirements need to be investigated and redesigned, or improved batteries need to be used in these applications. The possibility of reviving SMRs that give only their identifiers but not any other data needs to be explored. The SMR probe calibration needs to be verified by taking probe measurements in controlled soil conditions in a laboratory setting. This also could generate data that could be used to calculate moisture content from the resistivity data.

6. VISUAL PROBE

6.1 Introduction

Visual probes, as shown in Figures 1 and 2, are constructed from steel rods, stabilizers, tool joints, and Lexan tubes. The steel rods, stabilizers, and tool joints form a framework inside the Lexan tube that becomes sections of the visual probe. The first section of a visual probe has a drive point and is advanced into the ground using a sonic drill rig. Additional sections, 4 ft long, are added to the visual probe as needed to reach the required depth. The interior of the probe then provides access to the interior of the landfill or subsurface soil structure, and the waste or soil structure can be viewed through the clear Lexan tube. *OU 7-13/14 Integrated Probing Project Type B Probes Visual Probe Design* (Clark 2001b) describes the construction and design specifications of the visual probes installed for this program.

Ten visual probes were placed in the SDA. Three each were placed in the organic sludge focus area (743), the depleted uranium focus area, and the Pit 9 focus area (P9). One was placed in the americium and neptunium focus area (741). The locations of the probes are shown in the figures in Appendix A, and the detailed data for each probe are contained in the table in Appendix B (see Table B-1).

6.2 Methods

The procedure for the logging of the video probes is TPR-167l, "Visual Probe Logging Procedure." This procedure uses a commercially available borehole camera and records the visual images on standard VHS videotapes. The borehole camera uses a small diameter fiber optic cable that is lowered down the visual probes. The end of the fiber optic cable has a lens and light source, and the end can be articulated or bent up to approximately a horizontal position to see the side of the hole through the Lexan tube. The borehole camera has provided good images of the materials penetrated by the visual probes but has some disadvantages. The fiber optic cable is very difficult to hold steady inside the visual probe, so polyvinyl chloride (PVC) pipe slightly smaller than the inside diameter of the visual probe is being used to stabilize the fiber optic cable and steady the picture. This has greatly improved the quality of the borehole camera images. The borehole camera also has a small field of vision, so it is difficult to visualize the 360-degree image of the waste at each depth. The borehole camera has been used to log all of the visual probes, except P-9-9V, which only penetrated the clean soil on top of the landfill and 743-18V, which is so heavily corroded on the inside of the probe that rust particles collect on the camera lens and prevent the camera from recording a good image. The videotape borehole logs are available in the project files and the Hydrologic Data Repository.

During the summer of FY 2002, the visual probes were logged with an optical televiewer by a technical services contractor. The optical televiewer is a visual logging tool that can take a picture of the entire 360-degree interior of the visual probe in thin horizontal slices. The horizontal slices are placed in a digital file to create a complete visual record of the interior of the probe. The optical televiewer uses a rotating mirror in the end of the tool to illuminate the wall of the borehole and take the circumferential pictures. The images are displayed by splitting the image longitudinally and laying the image out flat similar to cutting a tube longitudinally and opening the tube up and placing it flat on a table with the interior surface facing up. All of the visual probes were logged with the optical televiewer, except for 743-18V and the visual probes in Pit 9. The visual probes in Pit 9 were not logged because construction activities for the retrieval demonstration prevented access to the probes. The images are available in the project files on a share drive, Hbb2/opitcal televiewer, or in *Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999-2002* (Josten 2002b).

6.3 Results

The logging with the borehole camera evolved into an effective technique to observe and evaluate subsurface waste and soil structure. The technicians operating the borehole camera started the logging efforts learning how to use and operate the borehole camera system and being challenged to find ways to produce steady images with a thin fiberoptic cable hanging down the inside of the visual probes. They gained experience operating the system and developed a way to stabilize the fiberoptic cable by running it through a PVC pipe that prevented the end of the cable from moving around so much and provided directional control. The borehole camera provides good micro-scale images of borehole interior. The borehole camera logs of P9-20-V are especially interesting. This probe is 12.6 ft deep, and the borehole logs show many features of buried waste, such as moisture, waste voids, yellow personal protective equipment, plastic sheeting, a drill bit, a shiny drum edge, and the soil waste interface. The other borehole logs display many of these same features but P9-20-V is the most interesting borehole log containing many different interesting features. The other borehole logs are available in the project files.

The optical televiewer provides a good macro-scale image of the interior of the visual probes. The image of 741-08-V shows the cover soil over the americium and neptunium focus area in Pit 10. Near the bottom of the log, a layer of yellow and translucent waste is shown, which is probably personal protective equipment. Probes 743-03-V, 743-08-V, and 743-18-V are in the organic sludge focus area in Pit 4. The log of 743-03-V shows a change in soil texture between 5 and 7 ft, and a distinct change in soil color below 7 ft that can be attributed to the presence of waste. The log for 743-08-V has recorded some very distinct waste near the bottom of the hole that appears to be light blue in color and cloudy or translucent. It’s difficult to determine what this waste could be, but it may be some translucent plastic sheeting the probe has penetrated. The discoloration of the Lexan also could be caused by carbon tetrachloride degradation of the polycarbonate. Probe 743-18-V cannot be logged because rust and corrosion on the inside of the probe collects on the clear plastic window of the optical televiewer and makes it impossible to get a good image. DU-08-V, DU-10-V, and DU-14-V are in the depleted uranium focus area in Pit 10. The log of DU-08-V shows overburden soil down to a depth of about 7 ft where a white object can be seen in the soil. Below this depth, the color changes to a lighter brown, and darker colored objects and fragments can be seen to the bottom of the probe. DU-10-V is a short probe and shows a distinct change in soil color at a depth of approximately 7 ft, which may be the overburden and waste interface. The log for DU-14-V has dark areas showing up in the soil below a depth of 7 ft and below 10 ft down to the bottom of the probe. At about 1 ft more, several dark images are seen that may be fragments or large pieces of waste. The depths in the optical televiewer logs are based on the collar of the probe and have not been adjusted for probe stickup.

6.4 Conclusions

The visual probes are a useful tool to gain access to and record images of the subsurface soil and waste. The visual probes coupled with the optical televiewer provide information that can define waste and soil interfaces, changes in color in the waste and soil matrix, images of waste fragments and pieces. The borehole camera provides images on a much smaller scale and is useful for examining smaller features and details in the borehole. It is interesting to note that the borehole camera has shown voids in the P9-20-V borehole that appear to be very large because the borehole camera has a small field of view that is displayed larger on the TV monitor. Voids recorded by the optical televiewer appear to be small spaces in the waste and soil matrix or horizontal voids caused by the driving of the probes. It would be very interesting to compare the two logs for P9-20-V, but scheduled activities prevented the logging of the P9 probes with the optical televiewer. The visual probes have provided a unique opportunity to physically see the soil and waste in selected parts of the SDA. While current plans for remedial activities do not include the use of the visual probes, they can be used again if experience with ongoing activities indicates visual probes would be beneficial.

7. TYPE A PROBES NUCLEAR LOGGING DATA

7.1 Methods

Analysis of Type A nuclear logging data continued during FY 2002. While a majority of the work performed this fiscal year represented compilation and publication of previous informal analysis, some new analysis was conducted. The new work was more quantitative in nature than previous efforts, marking advancement toward a more in-depth analysis to address very specific program objectives. New approaches for converting raw logging measurements into contaminant mass estimates were at the center of attempts to estimate VOC chlorine mass associated with Rocky Flats Plant (RFP) 743 sludge waste and Pu-239 mass near Pit 9 Probehole P9-20.

7.2 Results

The following list of FY 2002 Type A logging program activities reflects an effort to capture and document the status and history of the program through the end of logging in July 2001. In addition, initial steps were taken toward more advanced quantitative analysis of the data.

7.2.1 Compilation of Logging Database—October 2001

The downhole logging subcontractor, GTS Duratek, completed all contracted Type A logging field operations in July 2001. Duratek processed the new data (collected May through August 2001) and delivered spreadsheet summaries of these data in September 2001.

These new data were integrated into the logging database during October 2001. At this time, the entire logging data inventory, which encompassed data collected between June 1999 and July 2001, was examined for consistency and completeness. Several data conflicts, which arose because of changes in the GTS data processing methodology, were identified and corrected. An archive of raw spectral files was created and examined to determine that INEEL had received a spectral file for all measurements conducted during the downhole logging campaign. Missing spectral files were requested and received from GTS Duratek. Finally, the logging data were prepared for transfer to an INEEL data archive. The raw spectral files were provided on a CD and will be loaded onto a database for access by project staff.

7.2.2 Data Analysis Recommendations—October to December 2001

During October through December 2001, the OU 7-13/14 Project conducted a review of the technical objectives for the Type A downhole logging program. The objectives were:

- Derive a defensible release factor that describes the tendency for uranium, plutonium, americium, and neptunium within RFP waste to become soluble and mobile under the influence of ground water percolating through the SDA vadose zone

- Determine the amount and location of suspected neptunium and thorium enrichment within the logging campaign areas of the SDA

- Determine the Pu-239 mass distribution within the vicinity of Probehole P9-20

- Derive an independent estimate of the carbon-tetrachloride mass remaining in the SDA subsurface.

In addition to the review, a three-tiered technical approach was developed for achieving the downhole logging objectives where each tier produced increasingly detailed and quantitative information but at the cost of increased complexity and technical risk. Personnel requirements also were estimated. The document produced by this effort thus provides a basis for weighing the cost-benefit tradeoff for pursuing additional data analysis. The final document is attached as Appendix K.

7.2.3 Analysis of Residual Volatile Organic Compound Mass—October 2001 to January 2002

A preliminary study was conducted to evaluate the use of Type A logging data for estimating the amount of residual organic chlorine mass remaining in the SDA subsurface. An estimate of the original amount of chlorine mass was computed from waste inventory disposal records produced by Rocky Flats upon shipment of waste and by INEEL upon receipt and burial of RFP shipments. The current amount of chlorine mass is expected to be reduced from its original value because of leakage of drums, steady volatilization of VOCs into the vadose zone, loss to the atmosphere, and the action of the soil gas extraction project that has been operating at the SDA.

The method employed in this study was to examine organic chlorine in the vicinity of 41 probeholes located at the eastern end of Pit 4. Neutron-activated gamma-ray logging data for these probes include a peak height measurement for the 1,165-keV gamma ray, which is emitted during neutron capture reactions by chlorine nuclei. A methodology was developed for using the 1,165-keV gamma ray to estimate the total chlorine mass within an annulus surrounding the probehole. This mass was then compared with the original mass estimates to determine the percentage of CCl_4 remaining. Results indicate that the minimum fraction of chlorine remaining in the subsurface is 0.5 with a standard error of 0.16.

The study includes an in-depth uncertainty analysis. Calibration uncertainty for the logging tool was found to be the largest component of uncertainty for the residual chlorine mass estimate. The report gave recommendations for reducing this uncertainty component. The chlorine mass analysis report is currently pending publication (see Footnote C).

7.2.4 High-Level Detection Summary for Remedial Investigation/Feasibility Study—November 2001 to March 2002

A Type A logging results summary was included in an SDA risk analysis report issued in September 2002 (Holdren et al. 2002). For this report, data were organized by contaminants of concern and included Pu-239, Am-241, Np-237, U-238, U-235, Cs-137, and chlorine. The logging data were summarized to show high-level information, such as the total number of measurements performed; maximum, minimum, and average detected concentrations; number and percentage of nondetects; number and percentage of detections above risk-based concentrations; and number and percentage of detections above background.

7.2.5 Analysis of Evidence for Overburden Contamination at Pit 9—December 2001

Type A logging data were used to identify possible contamination in the Pit 9 overburden. This work supported preliminary engineering for a planned pilot-scale waste excavation at Pit 9. The overburden depth was first estimated based on logging data that reflect general soil media characteristics, such as moisture, natural radioactive elements, and soil-forming elements (Si, Fe, Ca). In many cases, the logging data showed a clear discontinuity of these media indicators in the 4.5–6-ft depth range, which was interpreted to mark the soil or waste boundary.

The data were then compiled to show all indications for Pu-239, Am-241, Np-237, U-235, U-238, Cs-137, Co-60, and chlorine within the upper 5 ft for probeholes of interest. No detections were found for U-235, U-238, Cs-137, and Co-60. Tables 16 though 19 show results for Pu-239, Am-241, Np-237, and chlorine.

The logging data show that radionuclide contamination occurs within the upper 5-ft soil layer but is confined (with two exceptions) to depths at or below 3.5 ft. Furthermore, the localized shallow contamination areas are continuous with contamination zones that reach their maximum apparent concentrations below 5 ft (P9-20 cluster and P9-03). Note that gamma radiation can penetrate through several inches of soil so that the point where the contamination actually begins is probably slightly deeper than the point where the logging tool first detects it. Taken together, these observations suggest that the majority of radionuclide detections above 5 ft are the result of a locally thin overburden, possibly combined with a small amount of radionuclide migration upward from the waste zone into the lower overburden soils.

The noted exceptions to the general conditions are one indication of Pu-239 (11 nCi/g at 3 ft in P9-20-02) and one indication of Am-241 (22 nCi/g at 1 ft in P9-20-03). These measurements had high uncertainties (29–30%). The spectra associated with these measurements were examined and showed the presence of contamination to be doubtful in both cases. It is suspected that the indicated levels of contamination in these two cases are below the detection limit for the count times employed. Chlorine indications for the 0–5-ft range may be described with the same general observations as for the radionuclides (Table 19).

In summary, the logging data show the overburden in the vicinity of the planned excavation to be clean, at least to the level of detection allowed by the logging tools and count times employed. For Am-241 and Pu-239, this detection limit is about 30 nCi/g. However, the overburden itself may be as thin as 3.5–4 ft in some places.

Table 16. Plutonium-239 occurrences (nCi/g equivalent) in the Pit 9 overburden based on spectral gamma-ray logging of Type A probes.

Pu-239 (depth)	P9-02	P9-03	P9-04	P9-05	P9-08	P9-09	P9-10	P9-11	P9-14	P9-19	P9-20	P9-20-01	P9-20-02	P9-20-03	P9-20-04	P9-20-05	P9-20-06
0.5																	
1																	
1.5																	
2																	
2.5																	
3													11				
3.5													170				22
4											194	309	422				390
4.5											2273	1148	994	170		827	3366
5		65									23920	3516	2104	1755		2907	11253

Table 17. Americium-241 occurrences (nCi/g equivalent) in the Pit 9 overburden based on spectral gamma-ray logging of Type A probes.

Am-241 (depth)	P9-02	P9-03	P9-04	P9-05	P9-08	P9-09	P9-10	P9-11	P9-14	P9-19	P9-20	P9-20-01	P9-20-02	P9-20-03	P9-20-04	P9-20-05	P9-20-06
0.5																	
1														22			
1.5																	
2																	
2.5																	
3																	
3.5																	
4												81	69	19			42
4.5											349	204	160	32			488
5											2830	570	528	296		300	1332

Table 18. Neptunium-237 occurrences (pCi/g equivalent) in the Pit 9 overburden based on spectral gamma-ray logging of Type A probes.

Np-237 (depth)	P9-02	P9-03	P9-04	P9-05	P9-08	P9-09	P9-10	P9-11	P9-14	P9-19	P9-20	P9-20-01	P9-20-02	P9-20-03	P9-20-04	P9-20-05	P9-20-06
0.5																	
1																	
1.5																	
2																	
2.5																	
3																	
3.5																	
4																	
4.5																	9.4
5												8.8		3.1		8.4	31.4

Table 19. Chlorine occurrences (counts/second) in the Pit 9 overburden based on neutron activation logging of Type A probes.

Chlorine (depth)	P9-02	P9-03	P9-04	P9-05	P9-08	P9-09	P9-10	P9-11	P9-14	P9-19	P9-20	P9-20-01	P9-20-02	P9-20-03	P9-20-04	P9-20-05	P9-20-06
0.5																	
1																	
1.5											0.3						
2																	
2.5			0.7														
3																	
3.5																	
4																	0.3
4.5															0.3		4.4
5									0.7	0.9	0.9	1.9					12.4

7.2.6 Comprehensive Type A Logging Data Summary—January to June 2002

Type A Nuclear Logging Data Acquisition and Processing for Operable Units 7-13/14 and 7-10, issued in August 2002 (revised September 2002), constitutes a comprehensive summary of Type A nuclear logging activities from program inception through the time of publication (Josten 2002a). The report describes the logging program objectives, study area locations, logging equipment, data acquisition procedures, and data processing procedures and makes recommendations for the permanent archive of the logging data. Report appendixes contain a previously unpublished logging subcontractor report, subcontractor field procedures, and copies of all logging tool calibration records. This report contains no data interpretation discussion but provides an ideal starting point for any party wishing to become familiar with the SDA logging program.

7.2.7 P9-20 Plutonium-239 Mass Estimate—June to August 2002

New quantitative analysis was conducted to estimate the amount of Pu-239 mass in the vicinity of Type A Probehole P9-20. A Monte Carlo Pu-239 source model was constructed to simulate the Pu-239 distribution surrounding P9-20. The gamma-ray field created by the Pu-239 model was computed and compared with the data observed by nuclear logging. Approximate agreement between the modeled and observed gamma-ray fields demonstrated the applicability of the Monte Carlo method, but no refinement of the model was performed because of the cumbersome and expensive nature of the Monte Carlo modeling process. Instead, point-source modeling procedure developed by INEEL's P. Kuan was expanded to permit modeling of a point source located between three surrounding Type A probeholes (Jewell, Reber, and Hertzog 2002). The size of the point source was iterated to obtain a match between the calculated and observed gamma-ray fields in three adjacent probeholes. A family of solutions was found corresponding to a range of possible soil densities. The corresponding Pu-239 mass estimates ranged from 319 to 2,217 g. Modeling results were used to develop appropriate safeguards for the planned excavation of the soil surrounding P9-20.

7.2.8 Comprehensive Logging and Surface Geophysics Data Analysis Summary—August to September 2002

A large amount of previously unpublished Type A logging analysis results were collected and organized for publication. *Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002* (Josten 2002b) was cleared and released in December 2002. The report presents a wide variety of qualitative and semiquantitative analysis including:

- Surface geophysics and waste inventory records used to select Type A probe locations
- Summaries of Type A logging results organized by focus area
- Analysis of depth to top and bottom of waste
- Discussion of apparent Np enrichment
- Details surface geophysics analysis for the west SDA.

This report covers the time period from inception of the logging program in 1999 to the present.

7.3 Discussion

New documents published in FY 2002 are sufficiently comprehensive to permit future interested parties to understand and, if necessary, reprocess the logging data using newly developed methods or to answer new questions.

Initial attempts to produce quantitative mass estimates from Type **A** logging data showed that uncertainties regarding the **SDA** soil media will have a significant impact on the accuracy of quantitative results. The quantitative information is best expressed as an upper and lower bound about the actual quantity sought. In cases where reasonable values for **SDA** soil properties have been derived, quantitative estimation methods have been able to specify defensible upper and lower bounds for the first time (e.g., Pu-239 mass at P9-20) or narrow the range between the upper and lower bounds over previous attempts (VOC chlorine from 743 sludge). The efforts also show that evaluation of the soil conditions in the vicinity of Type **A** probes is a prerequisite for accurate quantitative analysis.

7.4 Conclusions

The history of Type **A** logging activities, data processing methods, and basic results have been successfully compiled, organized, and captured in INEEL publications.

Initial attempts to produce quantitative mass estimates from Type **A** logging data showed that uncertainties regarding the **SDA** soil media will have a significant impact on the accuracy of quantitative results.

7.5 Recommendations

A permanent archive for all Type **A** logging data and **SDA** surface geophysical data should be provided.

Quantitative analysis method for Type **A** logging data with particular emphasis on characteristics of the soil media in the vicinity of the probes should continue to be developed.

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